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The Significance of Septa and Sutures in Jurassic Ammonite Systematics

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ABSTRACT

A study of Stephanocerataceae and Perisphinctaceae of the Middle Jurassic demonstrates that the structure of the septa comprises a complex vault and pillar system which is functionally adapted to the dimensions of the tube so as to give maximal stability to the shell. Only through a study of the septum can we interpret the different forms of the suture and discriminate between important and unimportant features. Different septa may have analogous sutures, especially in the external parts. These septal patterns are strikingly consistent within subfamilies or families even where other features suggest overlap between the groups. Some parts of the septum are not adapted, but either retained from earlier ontogeny or inherited, and constitute vestigial (genotypic) characters distributed through taxons.

These empirical results have been applied to the taxonomy of some groups of hitherto doubtful systematic position (Cadomitinae, Normannitinae, Sphaeroceratinae, Parkinsoniidae, Spiroceratidae).

A. INTRODUCTION

FOLLOWING the recent article by the late W. J. Arkell (1957*b*), I would like to clarify my position regarding the phylogenetic interpretation of septal and sutural patterns in ammonoids. Reference is also made to the earlier reply by Schindewolf (1957). The method explained in this paper depends upon the dissection of a few well-preserved specimens of each genus or subgenus of which there are hundreds or thousands in museums.

Examination of the septum leads to a reduction of the number of possible interpretations of the suture, which is used as one of the mainstays of taxonomy. The most useful results can be derived from the fact that the septa show (*a*) a general structural plan, (*b*) correlation of their pattern with other shell features, (*c*) a variety of structural parts in each, (*d*) independent vestigial features, (*e*) different patterns with analogous sutures.

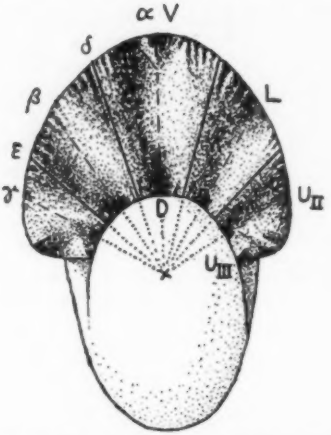
The curvature of the septum consists of a combination of three structural elements, which mostly coincide with suture patterns :—

(*a*) Convexity of the whole septum. Rarely as general bending of suture.

(*b*) Undulations over the whole of the septum, but enlarging from its centre in all directions (much more intensive than (*a*), which may not be distinguishable). Lobes and saddles.

(*c*) First and second grade fluting of the edge. First and second grade incisions.

Regarding the general convexity (*a*), Thompson (1942, pp. 840 ff.) explained the septal form of the recent *Nautilus* as conditioned by the membrane which builds the septa between a flexible body end and



TEXT-FIG. 1.—Front view of septum of *Macrocephalites* with strictly central support (abullate type, as in Text-fig. 2*a*) ; sutural elements as in Text-fig. 3. The thick lines indicate the top elements of the septal ridges, the saddle-axes ; the broken lines the bottom elements of the septal furrows, the lobe-axes. α median, β first, γ second lobe-axis ; δ first, ε second saddle-axis.

a less compressed chamber filling. Since the ammonoid septum is adorally convex, we must assume excess adapical pressure which is also indicated by the form of lobes and saddles in the suture (Arkell, 1957*b*, p. 243), whereas most nautiloid sutures suggest adoral excess pressure. Pfaff (1911, p. 211), on the other hand, explains the shape of the recent *Nautilus* septum as the adjustment of its own tension to the hydrostatic pressure transmitted through the body to the septum and thus to the tube.

Regarding the major undulations (*b*), Pfaff explained their high symmetry as due to the perfect adjustment of the septum itself to the whorl dimensions. After application of stress analyses to septa of Ammonitina, he finds that all septa are " mathematically exact "

complex vault structures under the same adoral pressure conditions as stated in (*a*) above. Ruzhencev (1946, p. 705) concluded from a study of Goniatitina and Prolecanitina that " the folds of the septum are located in a way as . . . to counteract the pressure of the water column . . . counteraction to the mechanical stresses of every kind that endanger the safety of the test. The complicated folding of the plate and the presence of vaults turned towards the aperture, i.e. against the force in action, secure the strength of the septum itself, and allow it neither to bulge out into the neighbouring air chamber nor the more so to be broken. The folds of the septum play a role of peculiar scaffoldings and are always so located that the test supported by them acquires a maximum resistance against the pressure from without. The completed study shows that the suture line, septum, and the whole of the conch are most closely interdependent both structurally and functionally ". Then Ruzhencev concludes : " That is why the suture lines . . . represent as before one of the basic supports in the work of the reconstruction of the history of ammonites," but he does not recognize that independent rather than interdependent characters are necessary to distinguish otherwise homeomorphic groups. Pfaff's hypothesis that the pressure in the chambers could not be equalized while the animal descended may partly be disproved (Arkell, 1957*b*, p. 243). However, the pressure compensation would not have been perfect : consequently, normal pressures from both sides as well as peripheral pressure and traction on the septum acted during descent and ascent.

Regarding the edge fluting (*c*), Pfaff found empirically that throughout ontogeny the length of suture varies directly as the projected area of the related septal surface (i.e. as the square of the septal diameter) and inversely to the thickness of the septum. Hence, the edge fluting gives the best fastening for the septum. Each fold is also looked upon as a vault. Thompson mentions only the form of the suture and explains the incisive form as a phenomenon of surface tension. Ruzhencev concludes, like Pfaff : " Tight fusion of the plate with the inner surface of the tube, multifold elongation of the line of contact due to the complicated folding of the outer margin . . . all this . . . counteracts the stresses tending to break off the septum from the walls of the test."

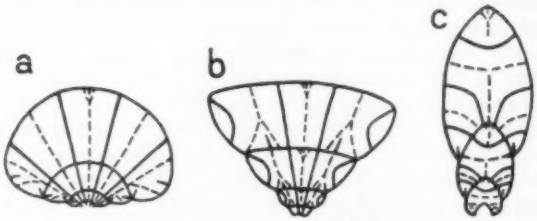
B. Patterns and Terminology of the Septal Undulation

The septa of the Ammonitina are divided by Pfaff into only two " main groups " which are here taken as primary types : (*a*) the lateral support (normal to the plane of symmetry) and (*b*) the central support (directed toward the embryonic chamber). A third and special

type may be added : (*c*) the radial support (directed to the centre of the septum).

Complete superfamilies or families can be assigned to one of the three types (considering ontogenies). The Stephanocerataceae and Perisphinctaceae examined from the Middle Jurassic belong to the centrally supported primary-type, with the exception of the radially supported Spiroceratidae.

Both Superfamilies (without consideration of Upper Jurassic peri-



TEXT-FIG. 2.—Saddle- and lobe-axes of the centrally supported primary-type rest, (*a*) in the bullate main-types only on preceding whorls and on homologous structural elements (*Emileia*), (*b*) in the planulate main-type mainly on preceding whorls and on both homologous and different elements (*Germanites*), (*c*) in the mature disculate tertiary-types only dorsal on preceding whorls and only on different elements (*Quenstedtoceras*).

sphinctids) show the following patterns in ontogenetic sequence (Text-fig. 4) :—

(i) *Nepionic Whorl* (*? Larval stage of tube, first whorl*).

(*a*) *Proseptum* (corresponding to Prosuture of Schindewolf).—Always has a median saddle-axis and one pair of saddle-axes. Accordingly its suture is fundamentally different from all later septa. Considering also its different mineralogical structure (Shrock & Twenhofel, 1953, p. 491) it probably still belonged to a larva-like stage (Westermann, 1954, p. 64).

(*b*) *Primary-septum* (corresponding to Primary-suture of Schindewolf, non Spath).—Always has median lobe-axis, like all later septa, and two pairs of saddle axes. Umbilical seam supported by the medially situated second umbilical lobe. The suture, therefore, has five lobes including only two umbilical ones ($U_{II} + U_I$ or U_{III}).

(ii) *Neanic Whorls* (*Juvenile stage of tube, second to fourth whorl*).

A significant change generally starts in the late first or early second whorl with a different support of the umbilical seam : (1) by the second saddle-axis ; its sutural saddle develops then by incising (forming auxiliaries) and widening the sutural " lobe " U_{III}, which

is really an extremely depressed saddle (*orthochrone* sequence of the lobes); (2) by the first lobe-axis with U_{III}; the second saddle-axis is laterally removed. Then a new lobe is built between U_{III} and D which, considering its position, is U_I. A complicated transformation of the septal patterns follows (*heterochrone* sequence of lobes). These features do not seem to correlate with whorl dimensions. They are generally recognizable in the suture throughout the ontogeny by the high or low position of the sutural lobe (normal or retracted "suspensive lobe") depending respectively on its origin from either a saddle (orthochrony) or a lobe (heterochrony). This character is, therefore, not limited to the early ontogeny, the "plastic young" of Spath and Arkell (1957*a*, p. L112).

(*a*) *Main-types*, appearing in end of second and in third whorl.

Bullate Main-types (shell sphaerocone, depressed).

1. *Eubullate*.—In the "orthochrone" type the pure double-axial central support persists.
2. *Abullate*.—In the "heterochrone" type an analogous pattern comes about by the growth of a new second saddle-axis.

Sutures characterized by the equal sizes of both the two outer and the two inner saddles; only differentiated by the height or depth, respectively, of U_{III}.

Planulate Main-types (shell platycone–serpenticone, whorl round).

3. *Euplanulate*.—In the "orthochrone" type by reduction of the second saddle-axis.
4. *Aplanulate*.—In the "heterochrone" type by new construction of an incomplete dorsal second saddle-axis.

Suture with dominating first (external) lateral and, in particular, internal lateral saddle; also differentiated in the height of the sutural elements, but mainly in the pattern of U_I.

These four main-types either stay throughout the ontogeny as in *Bullatimorphites* (1), Otoitidae, Macrocephalitidae (2), *Garantiana*, *Strenoceras*, *Infragarantiana*, *Infraparkinsonia* (3), Stephanoceratinæ and Normannitinae (4), or change into secondary-types.

(*b*) *Secondary-types*, appearing in third or fourth whorl, of planulate types only.

Derivatives of the Euplanulate Main-type (a3).

1. *Euflexulate type* (whorl subquadrate or slightly compressed).—Both saddle-axes are bent convexly towards the septum centre and join at the dorsal edge. Suture not differentiated.
2. *Eubulliplanulate type* (whorl relatively depressed and involute).—Both saddle-axes are equally straight and strong, but are joined

at the dorsal edge. Suture almost as in eubullate type, differing slightly internally : lateral saddle higher and U_I inclined.

3. *Euspirulate special-type* (cyrticone, whorl completely rounded).—Already formed in very early neanic stage (with opening of spiral ?), but is derived from the euplanulate main-type. Two main lobe-axes crossing at a right angle. In addition to the median-lobe-axis (V–D), therefore, the new lobe-axis U_{II}–U_{II} arises (U_{II} middle between V and D). Ventral half of septum exactly euplanulate. The suture has large U_{II} but small L and U_I ; because of the uncoiling, no sutural-lobe U_{III} is built.

Derivatives of the Aplanulate Main-types (a4).

4. *Aschizolate type* (gr. " split, divided ") (whorl already round in early neanic stage).—The first saddle-axis is reduced early by transverse division and sideward bending of the interior part. Suture not differentiated.
5. *Abulliplanulate type* (whorl depressed trapezoidal).—The lobe-axis straightens and a new incomplete second saddle-axis is formed, nearly analogous to abullate. Suture also resembles bullate, but shows inverse height ratio of the internal saddles.

These types stay throughout the ontogeny as in *Praebigotites*, (?) *Leptosphinctes* (1), *Oecoptychius* (2), *Spiroceras* (3), Siemiradzkiinae (4) (p. 448), and Cadomitinae (5), or change once more, but invariably in post-neanic stages (tertiary types).

(iii) *Ephebic Whorls* (*Adult stage of whorl, fifth to seventh/ninth whorl*).

(*a*) *Tertiary Disculate Types* (whorl very compressed).

Derivatives of the Euplanulate Main-type.—Reduction of the median-lobe-axis and building of new lateral supporting saddle- and lobe-axes bent convexly towards the septal centre. The two types are almost or completely homeomorphous ; the sutures are unchanged and also homeomorphous :—

1. *Euplanodisculate type.*
2. *Euflexudisculate type.*

Derivatives of the Abullate and Aplanulate Main-types.—The axes are transformed as in the analogous *eu*-types.

3. *Abullidisculate type.*—In spite of the extreme change of the whorl section (septum outline) the septal edge (suture) preserves its pattern. Especially remarkable are the two very narrow, high internal saddles with the very deep U_I (Text-fig. 4).
4. *Aschizodisculate type.*—Septum analogous to the other disculate types. Suture not differentiated.

To these types belong a number of perisphinctids (1, 2), the Cardioceratidae, Kosmoceratidae (3), and parkinsoniids (4).

C. General Regularities of the Septal Undulations

(i) *Adjusted, Adaptive Features.*

The different septal patterns seem to demonstrate general rules of vault structure :—

(*a*) The longitudinal axes of the undulations (saddle- and lobe-axes) : (1) follow the shortest distance across the septum, and (2) end perpendicular to the tube (projected on to a plane at right angles to the axis of the tube). (3) The top and bottom elements are the stiffest supporting elements of the undulations. (4) They support the stiffest parts of the tube, i.e. the umbilical seam and side angle. (5) Centrally (adapically) directed top and bottom elements join similar elements of the anterior whorls (Text-fig. 2). (6) Top and bottom elements have approximately equal stability.

(*b*) Size of the undulations : (1) Span is proportional to length. (2) The central part of the septum tends towards a flat surface.

In accordance with these regularities all septa here studied can be looked upon as complex vault and pillar constructions adjusted to normal pneumatic or body pressure (vaults) and peripheral hydrostatic pressure and tension (D, p. 448) (pillars). The structures also result in a protection from external stress from any direction. The nature of the vault structure strongly suggests that it is conditioned by functional adaptation.

Hence the septal shape correlates with almost all dimensions of the tube.[1] This adjustment, however, is imperfect and there are also non-adjusted (non-adaptive) features ; Pfaff, Ruzhencev, and Arkell (1957*b*, p. 242) seem to discount these. But they, too, use these proper characters for taxonomy at high and low levels.

(ii) *Not Adjusted, Non-adaptive Features.*

A number of regular septal features, often also distinct in the sutures, nevertheless cannot be explained mechanically as above : (1) The transformation of the proseptum into the primary-septum, similar in all Ammonoidea ; no clear differences within the groups examined. (2) The different support of the umbilical seam. (3) The early junction of the second (ventral) saddle-axis with the first in the euspirulate septum. (4) The narrowness and height of both the internal lateral saddles in the adult abullidisculate septum. (5) Some overlapping in the whorl dimensions of the bullate and planulate septal types.

Regarding (2), Schindewolf (1953, pp. 123–8 and previous papers) assumed that all Stephanocerataceae as then understood, as well

[1] I accept some blame for Arkell's (1957*b*, pp. 241 and 242) complete misunderstanding of the corresponding sentence in my previous paper (1956*a*, p. 237).

as all Parkinsoniidae, " Pseudoperisphinctidae " (= Siemiradzkiinae), Reineckeiidae, Peltoceratidae, and Zigzagiceratidae show heterochrony, whereas the majority of the Ammonoidea show orthochrony. Accordingly he characterized the Stephanocerataceae by their heterochrony, included all families with this anomalous lobe sequence, and gave superfamilial rank to this character. Recently, however (Westermann, 1956, pp. 258, 269 ff.), orthochrony was discovered in *Bullatimorphites*, in the early (*subfurcatum*-zone) " *Parkinsonia* " *inferior*, consequently separated as *Infraparkinsonia* but unquestionably ancestral to the heterochrone *Parkinsonia*, and in *Garantiana* and *Strenoceras*. *Garantiana* and *Parkinsonia* at least seem to belong to the same subfamily. Accordingly the different support of the umbilical seam ranks at the level of subfamilies and families, and rarely even at generic level.[1] Certainly this character cannot be called " one more example of the vagaries of the ' plastic young ' " (Arkell, 1957*a*, p. 112).

Regarding (3), the ventral half of the *Spiroceras* septum strikingly resembles septa of normally coiled genera where this pattern makes sense mechanically.

Regarding (4), Kosmoceratidae and Cardioceratidae may have received their adult internal suture pattern only from an abullate septum. Their abullate neanic septa resemble completely the neanic and ephebic septa of the ancestral Macrocephalitidae.

Regarding (5), *Chondroceras* [Otoitidae] shows a wide range of dimensions and greatly overlaps morphologically in platycone forms (subgenus *Schmidtoceras*) with the Stephanoceratidae. The different septal types, however, show a fixed limit. Some Otoitidae in Australia resemble Normannitinae [Stephanoceratidae] in dimensions and ornament, but possess a typical bullate septum.

Consequently the regular shapes of the septa are not only caused by functional adjustment (adaptation) to the whorl dimensions but also possess independent characters that may very well be used in taxonomy. They are inherited or have persisted from preceding ontogenetic stages in which they were mechanically useful.

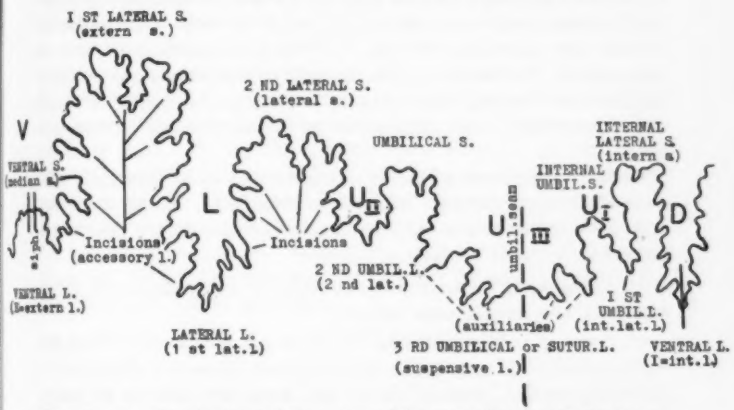
D. Folding of the Septal Edge

The fluting of the septal edge (incision of suture) starts in early or middle neanic whorls, lengthening (in suture) in approximate proportion to the square of the septum diameter (p. 443). Form and size of the single first and second degree folds are quite variable ; the trend toward a tripartite-trifid saddle and lobe division is almost the

[1] If Schindewolf's (1957, p. 439) suggestion that the Tulitidae on account of their parabolae might possibly belong to the Perisphinctaceae, is correct, the superfamily Stephanocerataceae may still be completely heterochrone.

only regularity in their arrangement. But there is quite frequently a differentiation in the intensity of the fluting at the level of subfamilies, genera, and often even of subgenera (Westermann, 1954, p. 73 ; 1956*b*, p. 42). The general intensity of incision is, therefore, probably the lowest-ranking sutural feature. This may be caused by different thickness of the septa.

A bifid second umbilical lobe can be found, rather irregularly, in different Stephanoceratacеae with little incised adult sutures, all of which belong to broad (depressed) bullate septa (Tulitidae, Otoitinae,



TEXT-FIG. 3.—Terminology of the suture of the centrally supported primary-type. Designation of saddles above, of lobes below. Synonyms between parentheses.

Sphaeroceratinae). But bifid lobes also occur in senilely reduced sutures. There is, however, transition from normal trifid to bifid lobes, in ontogeny as well as within a species or subgenus. This pseudo-bifid pattern seems to be merely a functional adjustment of the septal edge, to strengthen an especially broad but little fluted lobe-vault supporting the side angle as the most strained part of the whorl. Hence, its usefulness for taxonomy and inference of evolutionary trends is questionable.

E. Important and Unimportant Sutural Characters

(i) *Taxonomically Important Characters* of the adult sutures (Text-fig. 3) of Stephanoceratacеae and Perisphinctaceae of the Middle Jurassic are therefore :—

(*a*) *Whole suture.*—General intensity of incision. No relation to septal type.

(*b*) *External* (*ventral*) *region.*—(1) Relative size of the first and second lateral saddles. Distinction between bullate and planulate types. (2) U_{II} much smaller or much larger than L. Distinction between the spirulate type and all others.

(*c*) *Region of the umbilical seam.*—(1) Shallow or deep U_{III} (normal or retracted " suspensive lobe "). Uncertain distinction of *eu-* from *a*-types (ortho- or heterochrony).

(*d*) *Internal* (*dorsal*) *region.*—(1) Two similarly-sized saddles or a single, strongly dominant one. Sharp distinction of bullate and bulliplanulate types from planulate ones. (2) Umbilical saddle of similarly-sized saddles larger than the lateral saddle or not. Distinction of bullate from bulliplanulate types. (3) The same accessory to U_{III} or independent. Distinction of eubullate and eubulliplanulate types from abullate and abulliplanulate ones. (4) U_I large and deeper or small and shorter than U_{III}. Distinction of euplanulate from aplanulate types.

Evidently the internal sutural characters are more numerous and more clearly differentiated than the external ones, but in the main only the external suture has been examined and used for taxonomic purposes.

(ii) *Unimportant Characters* or characters of very questionable value within the two superfamilies include :—

(*a*) *Form of saddles and lobes*, such as the pseudo-bifid U_{II}-lobe which Arkell (1952, pp. 84 ff.) regards as one important character in distinguishing the " genera " *Tulites* and *Rugiferites* (later in the same paper *Rugiferites* is only a subgenus) and in drawing evolutionary lines (1957*b*, p. 239).

(*b*) *Arrangement of incisions and form of the individual incisions.*—Arkell's (1957, pp. 236–240) minute details should obviously be considered as free variation without taxonomic value, but they cannot be advanced as arguments against the septum theory. There is, however, no justification for his (1951, p. 35) subdivision of *Clydoniceras discus* into five, mostly newly-named varieties, which are established on account of these details.

F. Phylogenetic Application and Taxonomy of Stephanoceratacеae and Perisphinctaceae [1]

The application of the septal structures or of their sutural characters to phylogeny may be (1) by analogous arrangement on the basis of

[1] The subfamilies Morrisiceratinae, Bigotitinae, and the questionable Berbericeratinae as well as the genus *Infragarantiana* and the subgenera *Chondroceras* (?) (*Praetulites*) and *Leptosphinctes* (*Praeleptosphinctes*) were established on other than septal and sutural characters (Westermann, 1956*a*, pp. 257–271).

equivalent septal types, or by inferring evolutionary relationships from (2) the similarities and suggested transformation trends of septal types or (3) from the similarities of the non-adaptive septal characters.

(*a*) *Reclassification of Otoitidae and Omission of* " *Sphaeroceratidae* ".

A study of all Bajocian Stephanoceratacеae with lappets (" Otoitidae ") necessitated their subdivision into Otoitinae and Normannitinae (Westermann, 1954, p. 72) on account of the sutures. Their differentiations correspond with the abullate and aplanulate septal main-types (Text-fig. 4) which rank at the family level. The limit is well established considering that all of Arkell's " missing links " (1954, p. 568) from Australia seem to be abullate and tend only late in maturity toward platycone whorl-shape (Westermann, 1956*a*, p. 249). Of the Normannitinae badly preserved or incomplete *Itinsaites* and *Epalxites* often cannot be distinguished from other Stephanoceratidae (ibid., p. 247). On the other hand, there is as yet no reasonable distinction of the Otoitinae from the Sphaeroceratinae (Sphaeroceratidae auct.). The most " natural " taxonomic procedure is, therefore, to place the Normannitinae [1] (*Normannites*, *Itinsaites*, *Epalxites*, *Germanites*, and *Masckeites*) with the Stephanoceratidae. However, the Otoitinae are reunited with the Sphaeroceratinae in the Otoitidae (syn. Sphaeroceratidae).

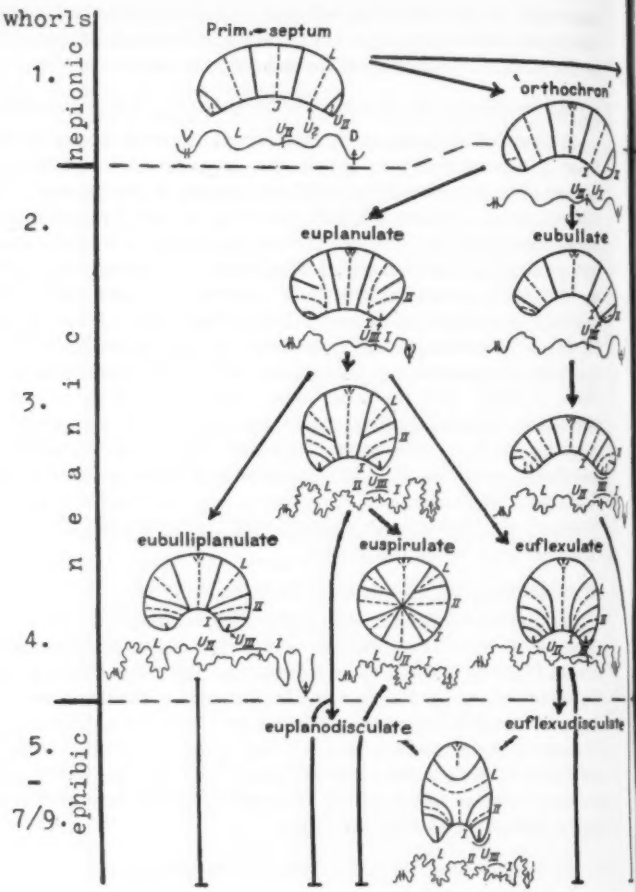
(*b*) *Establishment of Cadomitinae Westermann, 1956.*

Cadomites and the similar *Polyplectites* differ from all other Stephanoceratidae in their abulliplanulate septa, also distinctly shown in the sutures (Text-fig. 4), as well as in ornament and shape. They arise at the base of the upper Bajocian, while all the rest of the family becomes extinct. Arkell's objection (1957*b*, p. 249) that " the distinction of *Cadomites* from *Stephanoceras* is so delicate " seems therefore unfounded. That " there are still hardly any that succeed in using the name *Cadomites* correctly " is a nomenclatorial confusion rather than a taxonomic one (Spath, 1944).

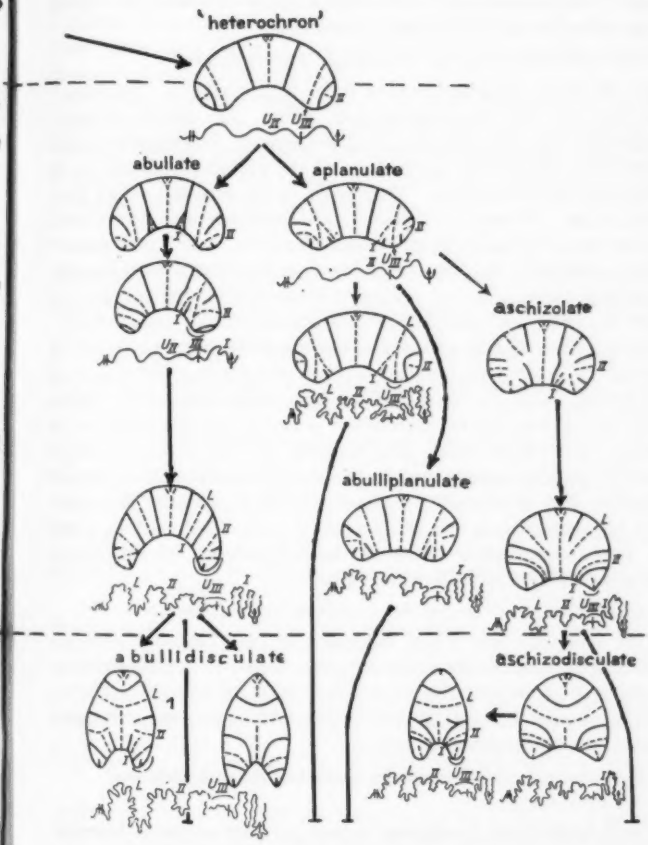
(*c*) *Reclassification of Spiroceratidae and Omission of* " *Spiroceratacеae* ".

The transformation of a planulate into a spirulate septum, hence

[1] Arkell (1957*a*, p. L289 ; 1957*b*, p. 244) considers them as a single genus, but they show as much differentiation as all the rest of the Stephanoceratidae which are subdivided into at least six well-defined genera. *Normannites* and *Itinsaites* (syn. *Metaxytes*, *Kanastephanus*) both have world-wide distribution and resemble *Stephanoceras* or *Phaulostephanus* and *Stemmatoceras*. The quite different *Epalxites* is restricted to the *sauzei*- and basal *humphriesianum*-zone and resembles *Teloceras*. *Germanites* differs by its compressed whorls and its ornament, and even had recently (Westermann, 1956*a*, p. 251) to be subdivided. The single specimen of *Masckeites* resembles *Polyplectites*.



also its abnormal suture (Text-fig. 4, lower left), can be explained by its functional adjustment (p. 448). The ventral half of the *Spiroceras* septum strikingly resembles the euplanulate septa of *Strenoceras*, *Garantiana*, *Infragarantiana*, and *Infraparkinsonia*, the first of which is very similar in ornament. Therefore, we may be sure of the descent of the uncoiled *Spiroceras*, *Apsorroceras* (subgenus ?), and the derived *Parapatoceras* from the normally coiled *Strenoceras* (or its ancestral Leptosphinctinae) (Westermann, 1956*a*, p. 272). Consequently we



TEXT-FIG. 4.—Transformation of septa and corresponding sutures in ontogeny and evolution of the Stephanocerataceae and of Perisphinctaceae of the Middle Jurassic. Building of main-types in early, and secondary-types in later neanic whorls, of tertiary-types in early ephibic whorls.

abolish the superfamily " Spiroceratacеae " Arkell. Their obscure placement in the Lytoceratina (Arkell, 1950, p. 359 ; 1957*a*, p. L205) was first contradicted by Schindewolf (1953, p. 123). The " Arcuceratidae " (Arkell, 1950, p. 359) appear highly dubious because they are

based upon only one doubtful specimen (Westermann, 1956*a*, p. 272).[1]

Using similar methods it may be possible to show that at least many " Ancyloceratacеae ", including the Ancyloceratidae, may belong to the Ammonitina as well (not Lytoceratina).

(*d*) *Leptosphinctinae and the Descendant Parkinsoniidae.*

In the basal *subfurcatum*-zone there is a typically " explosive " evolution of the Leptosphinctinae within the *phaulus*-subzone. Apparently the *Leptosphinctes*, *Phanerosphinctes*, *Praebigotites*, *Infragarantiana*, *Infraparkinsonia* possess all the euplanulate main- or its euflexulate secondary-type. They seem to be ancestral to all Perisphinctaceae. *Garantiana* certainly, and probably also *Strenoceras*, evolved from *Infragarantiana* Westermann (1956, type " *Garantiana* " *primitiva* Wetzel) ; they have equal septa and similar general features. Regarding dimensions and ornament *Parkinsonia* must have evolved from the older *Infraparkinsonia* Westermann (1956, type " *Parkinsonia* " *inferior* Bentz) which has only recently been separated on account of its own euplanulate septum and the aschizolate one of *Parkinsonia*. This evolution and the near relationship to *Garantiana* imply evolutionary transformations of septal main-types at as low as the generic level (p. 448). The apparent interval in this evolution from the middle *subfurcatum*- to the upper *garantiana*-zone may be related to this phenomenon. Hence, the Parkinsoniidae descended from Leptosphinctinae and are Perisphinctaceae; their inclusion with the Stephanoceratacеae, based on the heterochrony of *Parkinsonia* (Schindewolf, 1957, p. 438) is thus disproved.

(*e*) *Establishment of Oecoptychiinae Westermann, 1956.*

This subfamily was based especially on the eu(?)-bulliplanulate septum of *Oecoptychius* and tentatively traced back to Leptosphinctinae on the basis of the probable transformation of the septal type (1956*a*, p. 273), whereas Arkell (1957*a*, pp. L296, L311) refers the " Oecoptychiidae " to the Stephanoceratacеae.

(*f*) *Taxonomy of Morphoceratidae* (*including Reineckeiinae and Oecoptychiinae*).

The Reineckeiinae-[2] and their at least partially ancestral Morphoceratinae seem to differ from the Oecoptychiinae in their abulliplanulate

[1] Since this paper went to press D. T. Donovan and H. Holder (May, 1958, Neues Jahrb. Geol. Palaontol., Monatsh.) have concluded that " *Arcuceras martae* Potonié " is not an ammonoid, but conceivably a part of the stem or arm of a crinoid.—The authors also believe that Spiroceratidae derived from *Strenoceras*.

[2] Arkell (1957*b*, p. 246) may well be right in considering the " *Reineckeia* " from the N.W. German Upper Bathonian (Westermann, 1956*a*, p. 262) to be a probable *Parkinsonia*, but it would be the latest *Parkinsonia* known (ibid., 1958).

septa, to judge by the sutures given by Schindewolf (1953, p. 125 ; 1957, p. 436). But they, too, might have derived from Leptosphinctinae, considering their obviously perisphinctoid shell characters, involving a change of their septal main-type. Arkell (1950, p. 362) also tentatively places them this way, but mentions their intermediate morphoceratid-stephanoceratid characters.

Postulating stephanoceratid ancestors (Schindewolf, 1957, p. 438) we would either emphasize the septum and assume Cadomitinae, or the other features and assume Sphaeroceratinae; *Sphaeroceras* itself is homeomorphic to the earliest morphoceratid, *Dimorphinites*, with the exception of the latter's constrictions.

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Pyroxenes from the Dawros Peridotite and some comments on their nature

By A. T. V. Rothstein

Abstract

The paper contains eight analyses of primary and recrystallized pyroxenes from the layered ultramafic peridotite at Dawros. The assemblages in which these pyroxenes occur are compared to those from other peridotites and some comments are made on the pyroxene sequence. Consideration is also given to the problems arising as the result of the metamorphism of the primary igneous accumulate at Dawros.

EVIDENCE exists that the ultramafic peridotite at Dawros is of magmatic origin (Rothstein, 1957). Analyses of its pyroxenes are therefore published and some comments are made on their nature.

The Dawros peridotite is enclosed within the Connemara schists. Its history can be divided into three stages (op. cit., p. 20). First a series of layered rocks accumulated under the action of fractional crystallization, the influence of magmatic currents, and the gravitational separation of crystals and melt. In consequence the rhythmic series of dunites and pyroxenites possesses a cryptic variation associated with other features due to the relative motion of crystals and melt. (This type of variation has been fully described by Wager, 1953, p. 336.) The main sequence of rocks is illustrated in Text-fig. 1 and the cryptic variation is revealed by the changes in the pyroxene assemblages. The pyroxenes of this stage are euhedral to anhedral, contain exsolution lamellae of the complementary pyroxene, and may enclose partially resorbed olivine. These pyroxenes are designated " primary " in Table 1. Secondly, the hot layered accumulate underwent deformation. This resulted in recrystallization which gave rise in the pyroxenites to a polygonal mosaic of pyroxene, free from exsolution lamellae and free from enclosed olivine. These are the " recrystallized " pyroxenes of Table 1. Lastly serpentinization occurred resulting in the replacement of olivine and orthorhombic pyroxene by serpentine, which in the case of the pyroxenes is present as bastite pseudomorphs. Analyses were not made of this last variety.

A diversity of material exists for comparison and it is possible to find similarities with particular peridotites from widely differing localities. Such a comparison is made in Table 2 on the basis of the pyroxene assemblages present. The peridotites at Webster-Addie (Miller, 1953) lie within a metamorphic terrain and have been subjected to deformation after emplacement. The other peridotites occur as nodules in basaltic rocks (Ross, Foster, and Myers, 1954) and as cognate inclusions in the kimberlite pipes of South Africa (Williams,

1932, p. 356). In all these peridotites olivine and chrome-spinel are the associates of the pyroxenes, although they may be absent in particular examples. Modal feldspar is not present and rock analysis R from Dawros shows a very low Al_2O_3 percentage. Associated with the changes in the Dawros pyroxene assemblages are variations in the Mg : Fe ratios of the minerals. In Text-fig. 2 the various pyroxenes are compared in groups. At Dawros and Webster-Addie the Mg : Fe ratio of the orthorhombic pyroxene appears to be higher in the assemblage OP than in the assemblage OP + CLP. A more extensive

Characteristic Rock Type	Pyroxene Assemblage	
LHERZOLITES	OP + CLP	N
WEHRLITES	CLP	
Chrome-spinel horizon	OP + CLP	R
HARZBURGITES	OP	I, P M L
DUNITES	OP scarce	

TEXT-FIG. 1.—*Position of the analysed pyroxenes in a generalized vertical sequence of the Dawros peridotite.* The total thickness is 500 feet. The Chrome-spinel horizon is intermittent in character. The location of the analysed pyroxenes in the Dawros area will be found on Plate V, Rothstein, 1957.

range of Mg : Fe ratios may exist within the peridotite inclusions in basaltic rocks since reference is made (Ross, Foster, and Myers, 1954, p. 703) to nodules of olivine and orthopyroxene occurring associated with other varieties in a basalt at Finkenberg near Bonn. At Dawros the associated changes in the pyroxene assemblages are the result of magmatic differentiation. It is of interest that separately all the pyroxene assemblages at Dawros can be matched by those of particular peridotites from widely differing environments, and it may be that similar processes of primary igneous differentiation are involved.

At Dawros a curious sequence exists between bronzite and diopside. At some points in the intrusion a wehrlite horizon lies immediately above the harzburgite thus marking the temporary disappearance of the orthorhombic pyroxene. As the three principal minerals involved are olivine and the two pyroxenes the relationship apparently approaches very closely the system diopside-forsterite-silica (Bowen,

TABLE 1.—CHEMICAL ANALYSES OF PYROXENES

Pyroxene	L	P_1	P_2	I	R	R	N	M	4645	R
Type	OP	OP	OP	OP	OP	CLP	CLP	OP	OP	Rock analysis
*Origin	R	P	R	P	R	R	P	M		
SiO_2	57·10	55·70	55·11	56·25	55·02	52·73	51·81	50·14	51·69	51·30
Al_2O_3	0·70	1·87	2·28	2·45	2·69	2·05	3·60	6·02	4·55	1·74
Fe_2O_3	0·60	1·13	1·03	1·07	1·81	1·00	1·08	1·83	0·55	2·38
FeO	5·21	6·47	6·52	7·15	7·18	2·37	3·48	15·38	16·51	5·32
MgO	34·52	32·72	32·98	32·38	32·13	18·05	16·77	24·58	25·74	27·36
CaO	0·62	0·95	0·82	0·83	0·48	22·57	22·13	0·30	0·50	8·44
Na_2O	0·07	0·05	0·04	0·14	0·02	0·16	0·21	0·06	0·03	tr
K_2O	0·03	0·01	0·01	0·04	0·01	0·01	0·02	0·05	0·02	tr
H_2O+	0·64	0·26	0·36	—	0·21	0·48	0·24	0·18	0·04	2·42
H_2O-	0·06	0·07	0·03	—	0·02	0·09	0·04	0·06	0·05	·12
TiO_2	0·17	0·10	0·10	0·22	0·12	0·25	0·21	1·05	0·15	·44
Cr_2O_3	0·27	0·44	0·29	—	0·34	0·43	0·38	0·26	—	·34
MnO	0·17	0·15	0·16	0·16	0·19	0·12	0·11	0·36	0·27	·15
NiO	0·04	—	—	—	—	0·03	—	0·05	—	—
Total	100·20	99·92	100·13	100·69	100·22	100·33	100·08	100·32	100·10	100·01
Ca	1·2	1·8	1·5	1·6	1·0	44·9	45·1	·6	1·0	
Mg	90·3	86·8	87·3	86·2	85·6	50·0	47·5	71·2	71·9	
Fe	8·5	11·3	11·2	12·2	13·4	5·1	7·3	28·2	27·1	
$\%Al_2$	1·3	2·9	3·3	3·2	4·1	3·2	4·8	9·1	5·3	
γ[OP]	1·674 ± ·001	1·680 ± ·002	—	—	1·683 ± ·001			1·704 ± ·004	1·690	
β[CLP]						1·679 ± ·003	1·684 ± ·001			
2V	+ 74 ± 2°	+ 83 ± 1°	—	—	+ 87 ± 1°	+ 55 ± 1°	+ 55 ± 1°	− 76 ± 1°	− 76°	

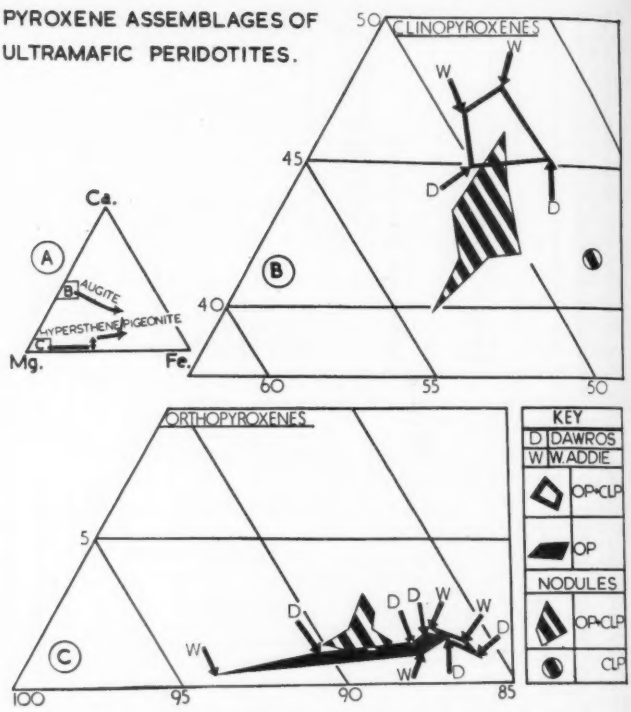
* P = Primary ; R = Recrystallized ; M = Metamorphic.

The minerals were separated by crushing, the use of heavy liquids, and a Frantz Isodynamic separator. The small percentage of impurities that remained were removed by handpicking. The analyses L, P, R, N, and M are by E. A. Vincent, analysis I is by B. A. Collet and E. A. Vincent, and rock analysis R is by R. A. Hall. Analysis 4645 is from Howie, 1955. The refractive indices of the Dawros pyroxenes were measured by a single variation procedure using a temperature control, their 2Vs were obtained by direct measurement from one optic axis to the other.

TABLE 2.—PYROXENE ASSEMBLAGES AND ASSOCIATED Mg : Fe RATIOS FROM SELECTED PERIDOTITES

Occurrence	Pyroxene Assemblage	OP. Ca	OP. Mg	OP. Fe	CLP. Ca	CLP. Mg	CLP. Fe	Locality	Reference	
Non-feldspathic peridotite	OP.	1·2	90·3	8·5				Dawros	Rothstein	$L P_1 P_2 I R N$
" "	OP.	1·8	86·8	11·3				"	"	
" "	OP.	1·5	87·3	11·2				"	"	
" "	OP.	1·6	86·2	12·2				"	"	
" "	OP. + CLP.	1·0	85·6	13·4	44·9	50·0	5·1	"	"	
" "	OP. + CLP.				45·1	47·5	7·3	"	"	
" "	OP.	·4	93·8	5·8				Webster-Addie	Miller, 1953	2
" "	OP.	1·1	87·2	11·7				"	" "	1
" "	OP. + CLP.	1·9	86·6	11·5	46·9	49·3	3·8	"	Ross, Foster, Myers, 1954	13
" "	OP. + CLP.	1·4	85·9	12·7				"	Hess and Phillips, 1940	4
" "	OP. + CLP.				47·8	47·6	4·6	"	Hess, 1949	1
Peridotite inclusion in basaltic rock	OP. + CLP.	1·9	89·1	9·0	44·6	49·1	6·3	Mexico	Ross, Foster, Myers, 1954	1
" "	OP. + CLP.	1·5	88·0	10·5	43·7	49·4	6·9	U.S.A.	" " " "	2
" "	OP. + CLP.	2·0	88·3	9·7	41·7	51·2	7·1	U.S.A.	" " " "	3
" "	OP. + CLP.	2·6	88·0	9·4	39·9	53·7	6·4	Germany	" " " "	4
" "	OP. + CLP.	1·4	89·9	8·7	41·7	52·0	6·3	Austria	" " " "	5
" "	OP. + CLP.	1·2	88·4	9·4				Manchuria	" " " "	6
" "	OP. + CLP.	1·2	88·3	10·5	46·1	48·4	5·5	Japan	" " " "	7
" "	OP. + CLP.	1·4	90·1	8·5	43·3	51·4	5·3	Hawaiian Is.	" " " "	8
" "	OP. + CLP.	3·2	88·0	8·8	41·9	50·0	8·1	Hawaii	" " " "	9
" "	CLP.				41·6	48·0	10·4	Hawaii	" " " "	11

Inclusions in Kimberlite	Number of inclusions in each group			Mine or fissure	
	OP.	OP. + CLP.	CLP.		
Pyroxene assemblages of peridotites of ultramafic type.	5	1	1	Not available	Bulfontein — Williams, 1932
	1			"	Dutoitspan — "
	2			"	Jagersfontein — "



TEXT-FIG. 2.—*Pyroxene assemblages of ultramafic peridotites.* Diagram A shows the position of the pyroxene fields of ultramafic peridotites with respect to the Augite series and the Hypersthene-Pigeonite series of saturated basaltic magma. (Diagram based upon Fig. 5, Poldervaart and Hess, 1951.) Diagrams B and C illustrate the relations between the pyroxenes from Dawros, Webster-Addie, and from the peridotite nodules in basaltic rocks.

1914). It may be that it is possible to consider some aspects of this pyroxene sequence in terms of the initial magmatic composition and the various liquidus-solidus relations within the system (Bowen, 1928, p. 49; Poldervaart and Hess, 1951, p. 478; and others). Additional factors may also exist such as water pressure. (Relevant here is the recent discussion on the course of crystallization of basaltic magma, Yoder, and Tilley, 1956, 1957).

It is possible that variations comparable to the changes in the Dawros pyroxene sequence occur in the peridotites of Belhelvie (Stewart, 1947), and also in the Old Red Sandstone hypersthene andesites of

the Midland Valley of Scotland (Tyrrell, 1914 and others). It is interesting to consider if the pyroxene sequence at Dawros is typical of a particular magma series and for this purpose a comparison is being made of these three groups of rocks.

Differences exist between the peridotites taken for comparison in this present paper. At Webster-Addie (Miller, 1953, p. 1139) the enstatite-pyroxenite is described as being within the websterite zone, while in the case of the cognate inclusions in the kimberlite pipes there are other varieties of peridotite, namely the garnetiferous and micaceous types (Williams, 1932, pp. 356–361 and Holmes, 1936, pp. 396–409). At Dawros further complications have been caused by recrystallization, although these effects are in the first instance small, being confined mainly to changes in grain shape (Rothstein, 1957, p. 13). However, one pyroxene, M, is very different from the others. It now most closely resembles some material from an ultrabasic charnockite (Howie, 1955, p. 754). It occurs in layers towards the top of the harzburgite, and so far transitional types to the adjacent normal layers have not been found. Associated with it are translucent green spinels and opaque ore. The pyroxene is strongly pleochroic. The analysis is marked by a high Al_2O_3 percentage which may be the result of the substitution of Al for Si under high pressure (Hess, 1952, p. 177). The Mg: Fe ratio is also much lower than that of the other Dawros pyroxenes. It is possible that this pyroxene originated entirely in the solid state, not necessarily solely from pre-existing pyroxene, and that it is a metamorphic mineral. An analysis of the spinel is not available.

These various features of recrystallization and transformation in the pyroxenes at Dawros may be indicative of metamorphic processes perhaps also affecting other ultramafic peridotites, although the individual circumstances vary. The Dawros pyroxenes, however, give an illustration of some of the problems which arise in a study of the primary igneous variation within these rocks, and they also indicate some of the difficulties which occur in making close comparisons between peridotites from different environments.

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The Bostonite of Rudh'a' Chromain, Carsaig, Mull

By D. S. Buist

Abstract

An account is given of the petrography and chemistry of the bostonite of Rudh'a' Chromain, Mull.

THIS rock is intimately associated with the composite sill of Rudh'a' Chromain, Carsaig, Mull, but is earlier in age. The bostonite sheet has apparently guided the intrusion of the composite sill.

A specimen taken from the centre of the bostonite of Rudh'a' Chromain has a specific gravity of 2·64 and is dark purplish-grey in colour. Sporadic crystals of black iron-ore can be distinguished on the polished surface.

In thin-section, the rock is composed of alkali feldspar, iron-ore, calcite, clinopyroxene, chlorite, and quartz. Straight or nearly straight extinction is characteristic of the feldspar and the mineral shows divergent crystallization in places. Alteration to calcite is usual and this tends to occur mainly in the centre of the crystals. Sporadic aggregates of feldspar and iron-ore are noted. The larger iron-ore grains frequently have a border of chlorite and/or calcite. Clinopyroxene is pleochroic from pale green to slightly darker green. Shreds of chlorite are sporadically distributed throughout the rock.

A chemical analysis, norm, and quantitative spectrographic analysis of the Rudh'a' Chromain bostonite are given in Table 1.

Table I.—Chemical Analysis, Norm and Quantitative Spectrographic Analysis of Bostonite, Rudh'a' Chromain

		Norm.		*Spectrographic analysis.*	
SiO_2	61·68	Q	8·40	Ba	500
TiO_2	0·34			Be	5
Al_2O_3	15·82	or	26·13	Co	3
Fe_2O_3	2·19	ab	42·15	Cr	1
FeO	4·27	an	7·23	Cu	10
MnO	0·15			Ga	40
MgO	0·44	di wo	1·16	La	200
CaO	2·02	di en	0·20	Li	30
Na_2O	5·09	di fs	1·06	Mn	5000
K_2O	4·42	hy en	0·70	Mo	1?
H_2O+	2·46	hy fs	6·73	Ni	15
H_2O-	0·84	mt	2·11	Pb	10?
P_2O_5	0·06	il	0·61	Rb	60
				Sc	10
	99·78			Sr	400
				Ti	2000
				V	2
				Y	200
				Zr	500

(expressed in parts/million)

Chemical analysis : W. H. Herdsman and D. S. Buist. Spectrographic analysis : D. J. Swaine.

A xenolith of black limestone taken from the bostonite proved to be fossiliferous and was examined by Mr. R. V. Melville of H.M. Geological Survey. His notes are given below :—

> "The fossils are not well preserved but they are probably Lias in age. I believe I can recognize *Chlamys cf. textoria* (Schlotheim), fragments of a small smooth pectinid like those commonly recorded as *Pecten calvus* (Goldfuss) and a fragment of a large *Pleurotomaria*. There are also fragments of a large, coarsely ribbed shell which may be portions of a large *Pseudopecten* such as *Pseudopecten acuticosta* (Lamarck) or *Pseudopecten equivalvis* (J. de C. Sowerby) and there is in addition much echinoid débris. Middle or high Lower Lias is possible."

Reference to Lee and Bailey (1925) suggests that this limestone may be a representative of the so-called Broadford Beds of Lower Lias age.

ACKNOWLEDGMENTS

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Palaeontological Evidence for the Age of the Carboniferous and Permian Rocks of Central Vestspitsbergen

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Abstract

Carboniferous and Permian fossils collected from Central Vestspitsbergen between 1938 and 1957 are listed according to formations and the age of each is assessed from these determinations. Resting unconformably on folded Devonian or metamorphosed Hecla Hoek the succession begins with plant-bearing continental facies and passes upwards into a marine succession with fusuline, coral and brachiopod faunas in limestones and dolomites associated with evaporites and cherts. Correlation with rocks elsewhere in Svalbard, which has been effected largely by lithological facies, is reassessed on palaeontological evidence; this consists of a sequence of plants from approximately Tournaisian to Namurian; of fusulines from the *Fusulina* Zone to the *Pseudoschwagerina* Zone, with the Carboniferous-Permian boundary falling in the middle of the Wordiekammen Limestones; and of brachiopods above this. The youngest fossils may be Upper Permian. The succession has few breaks and with further study will contribute to the correlation of Russian, West European, Greenland, and American rocks.

I. Introduction

DURING a series of expeditions from Cambridge to Billefjorden for investigations in Bünsow Land, north Dickson Land, and Ny Friesland, collections of fossils were made from rocks already known to be of Carboniferous and Permian age. The whole collection (including 172 plant specimens, about 600 fusulines from 34 sampling points, 213 corals, about 650 brachiopods, and smaller numbers in other groups) is in the Sedgwick Museum. Dr. H. C. Wang provisionally identified the material collected in 1938 and his records have been used for all except the fusulines and corals. Fusuline and coral material from all expeditions has been investigated by one of us (C. L. F.) and systematic descriptions are nearly ready for publication; all the other palaeozoological determinations of post-1938 material are his responsibility with the exception of the Bryozoa which were kindly identified by Mr. T. G. Miller. The identifications of Brachiopods in 1953 were carried as far as comparisons with the previously described Spitsbergen fossils of Holtedahl, 1913, Wiman, 1914, Frebold, 1937, and Wang, 1952 in Gee, *et al*; these sources have been indicated without dates in the lists (as also for the corals of Heritsch, 1939). The plant material is being investigated by another of us (N. F. H.) and the identifications listed below refer only to the macroflora. With work continuing in central Vestspitsbergen it is thought useful at this stage to bring together the fossil lists so far available from

each formation with some stratigraphical conclusions related directly to the succession as described in 1952 (Gee, *et al.*). At the same time a sequel to this last paper is in preparation on the geology of North Dickson Land in which, in addition to new material on Devonian rocks and structures, some of the outstanding 1949 observations on Carboniferous rocks will be included.

The material was obtained as follows. One of us (W. B. H.) made a small collection in 1938 (the main part of which was listed in Gee, *et al.*, 1952, p. 347). The bulk of the material was collected on the Cambridge Spitsbergen Expedition, 1949 (Harland, 1952) by Dr. O. P. Singleton. In 1951 Dr. M. H. P. Bott collected some marine fossils from Chydeniusbreen (Harland and Hollin, 1953), and one of us (W. B. H.) collected further plants from either side of Austfjorden in 1951 and 1953. In 1952 and 1954 small faunas were collected on

TABLE I.—STRATIGRAPHICAL SUCCESSION

Spitsbergen Nathorst, 1910		Central Vestspitsbergen Gee, *et al.*, 1952 (with modifications in this paper*)	Headings in Section II
Productusführende Kieselgesteine Spiriferenkalk	Brachiopod Cherts	Upper*	(*i*)
		Middle*	
		Lower* (" Lst. A." at base)	
Cyathophyllumkalk including Gipsschichten, Fusulinen Gestein P. Cora beds at base.	Cyathophyllum Limestones	Upper Gypsiferous Series	(*h*)
		Wordiekammen Limestones: Upper* (" Lst. B." at top)	(*g*)
		Wordiekammen Limestones: Mid*	(*f*)
		Wordiekammen Limestones: Lower* (" Black Crag " at base)	(*e*) (*d*)
Unterer Gipsstufe [in Billefjorden]	Campbellryggen Group	Passage Beds (and Pyramiden Conglomerates)	(*c*)
		Lower Gypsiferous Series	(*b*)
Kulm Sandstein	Culm = Billefjorden Sandstones*		(*a*)

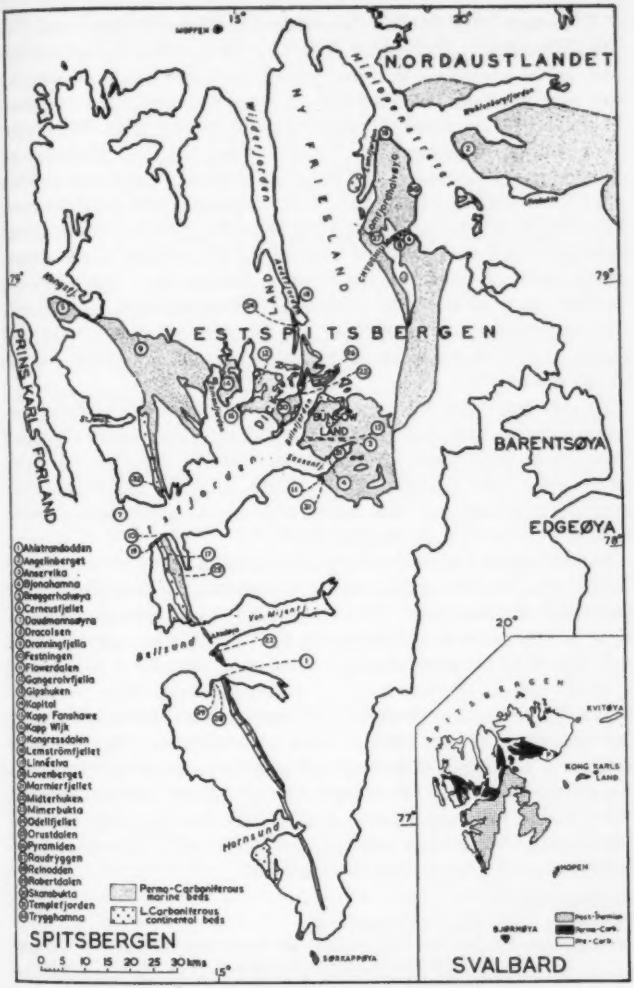
Dr. G. T. Wright's expedition to Tempelfjorden. Further plant material was obtained from north Dickson Land by Mr. B. Moore in 1955 and Mr. P. F. Friend in 1957.

Some modification of the stratigraphical scheme of Gee, Harland, and McWhae, 1952, has been adopted and this is shown in Table I. The fossils are grouped by stratigraphical units lettered II (*a*) to (*i*) under which all stratigraphical detail is from the same paper. It is already clear that continued study of this succession will allow further palaeontological subdivision.

II. The Succession in Central Vestspitsbergen

(*a*) *Billefjorden Sandstones*

The term " Culm-stuffe " was first applied in Svalbard (Heer, 1871) to rocks in Bjørnøya (Bear Island) thought to be at the top of the Lower Carboniferous and resting above the " Bergkalk-stuffe " with Productus and Spirifer Limestones (these in turn above the " Ursa-stuffe " of Cyathophyllum Limestone, sandstones, and shales with plants). The " Culm-stuffe " was correlated with *Posidonomya* beds



TEXT-FIG. 1.—Map showing the principal Carboniferous and Permian outcrops in Spitsbergen with localities mentioned in text. (Except for N.E. Vestspitsbergen the outline is from Orvin's map, 1942.)

and coals of Ireland and the Harz, and with the Millstone Grit of England. Nordenskiöld (1876) divided the Svalbard Carboniferous formation into three divisions : " A. The Lower Mountain Limestone

(" Ursa-stage "), " B. The Mountain Limestone Proper " and " C. The Carboniferous Formation Proper ". At that time the only proper coal seams known came from isolated exposures south of Bellsund and were naturally taken as coal measures (C), above the Mountain Limestone (B), whereas the plant remains known from Billefjorden were referred to group (A). By 1910 when Nathorst published his comprehensive account of the Geology of Svalbard, the general position of all Carboniferous plant- and coal- bearing beds above the redescribed Devonian Ursaflora, was shown to lie below the main marine carbonate deposits; they were grouped together as the " Kulm ", the typical development of which was described in Billefjorden. The Culm has generally been taken (Orvin, 1940) as a continental succession of Lower Carboniferous age and because of the variable developments of deltaic and lacustrine facies no general stratigraphical subdivision has yet been attempted.

As the term Culm has been used twice in Svalbard in different age-senses and elsewhere in at least two very different facies-senses, the name Billefjorden Sandstones is adopted here for the plant-bearing series below the Lower Gypsiferous Series and overlying the Devonian in central Vestspitsbergen. The term Culm is retained for general use in Svalbard in the sense of Nathorst 1910.

The Billefjorden Sandstones are typically sandstones with subordinate dark shales and coal seams, resting unconformably on folded Middle Devonian or older rocks. They occupied a trough running along the approximate position of Billefjorden and Wijdefjorden and the thickness (about 80 m. at Pyramiden) increases to the east of Billefjorden to about 200 m. Further south at Anservika about 100 m. has been recorded. To the north beside Austfjorden at least 500 m. is known at Odellfjellet and at least 300 m. from Lemströmfjellet. These outcrops are part of a continuous development possibly originally isolated from the deposits in western Spitsbergen, though possibly connected across Ny Friesland to Lomfjorden. All plant material from these scattered localities and horizons is combined in one list below pending results from the examination of the microflora.

PTERIDOPHYTA

Equisetales *Calamites* sp., pith casts

Lycopodiales *Cyclostigma* sp., part of stem resembling *C. pacifica* (Steinmann) figured by Jongmans, 1954, Pl. 23, fig. 29aa

Bothrodendron ? *wükianum* (Heer) of *B. kidstoni* group

Lepidodendron nordenskiöldii Nathorst, 1920, of the Sub-lepidodendron group which is considered by Lutz (1933) under *Lepidodendropsis*

**L. spetsbergense* Nathorst

**L. rhodeanum* Sternberg

L. ? *heeri* Nathorst. This is close to *Eusigillaria* of the Favularia group

**Lepidophloios scoticus* Kidston

Archaeosigillaria vanuxemi (Goeppert) Kidston
*"*Knorria*" spp. Frequent sandstone moulds represent decorticated Lepidodendra of several types
**Sigillaria* sp. (Favularia group)
Sigillaria sp. (Rhytidolepsis group)
**Stigmaria ficoides* (Sternberg) Brongniart
S. rugulosa Gothan in Gürich, 1923

PTERIPHOPHYTA (Macrophyllous) or PTERIDOSPERMAE
Sphenopteridium norbergii Nathorst
Adiantites bellidulus Heer
**Cardiopteridium* ? *spetsbergense* Nathorst, 1910, pinnules only
Cardiopteridium sp., pinnules only, resembling *Neurocardiopteris broilii* Lutz, 1933.

SPERMATOPHYTA
Cordaitales *Cordaites* sp., leaf only

Nathorst (1914, p. 84) summarized the plants then known from the Spitsbergen Culm. The fossils he listed from Billefjorden included the following :—

From Pyramiden those marked * on the list above and *Lepidodendron* cf. *nathorsti* Kidst.; *L. veltheimi* Sternb.; *Porodendron tenerrimum* (A. et Tr.) Zal.; *Porostrobus zeilleri* Nath., suggested by Chaloner (1958) on spore evidence that this should be *Selaginellites ; Sphenopteridium kidstonii* (Nath.) Pot.; *Sphenopteris bifida* L. & H.; *Carpolithus* spp.
From Gipshuken (outcrop is by shore north of Anservika) Nathorst records *Lepidodendron robertii* Nath. and *Spenopteris bifida* L. & H.

Amongst the new material (collected 1938–1957) many doubtful specimens have been rejected, but the list given above which amplifies that of Nathorst (1914) is considered to give an accurate picture of the whole collection. The only fossils present in great quantity are *Stigmaria ficoides* and "*Knorria*" spp., others being represented by three or four good specimens at the most.

The Billefjorden Sandstones, from the above evidence, are believed to span a large part of Lower Carboniferous time. Sub-Lepidodendra and *Cyclostigma* perhaps represent the earliest Dinantian and *Lepidophloios scoticus* is characteristic of the Calciferous Sandstone of Scotland (Walton, *et al.*, 1938), although there is no trace of the Upper Devonian "Ursa flora" of Bear Island. On the other hand true *Calamites*, *Sigillaria* spp., and *Cordaites* are all very rare before the upper part of the Carboniferous Limestone Series of Scotland (Crookall, 1932) ; *Stigmaria rugulosa* is not known before Namurian A in Europe and Witzig (1952) lists it from Namurian (A?) of East Greenland. It is possible that the succession will eventually be divisible on floral evidence.

(*b*) *Lower Gypsiferous Series*

Within the Campbellryggen group this evaporite facies has been shown to pass by lateral transition as well as vertically into the Pyramiden conglomerates to the west and the Passage Beds to the east of Billefjorden. The Series is dominantly gypsum with subordinate

anhydrite, dolomite, sandstone, and a little limestone. It varies in thickness from 0 to over 300 m., passes by alternation down into Culm, the base being defined by a conspicuous red sandstone.

From near the base indeterminate lamellibranchs, gasteropods, crinoid stem fragments, and echinoid spines were found. From near the top *Choristites* sp. was found, linking the upper part of the series with the overlying Passage Beds. *Choristites* does not appear in Russia until the topmost Namurian and becomes common low in the Moscovian (Semichatov, 1936), ranging into the Upper Carboniferous.

(*c*) *Passage Beds*

Penecontemporaneous dolomites predominate, with some gypsum in the middle of the trough and with pure limestone at the edge they pass down by alternating transition to gypsum. The thickness varies from about 40–200 m. The following species have been identified :—

Fusulinidae	*Profusulinella pararhomboides* Rauser *et al.*
	Eofusulina cf. *triangula* (Rauser *et al.*)
	? *Fusulinella eopulchra* Rauser
	Ozawainella sp. or spp.
	Pseudostaffella sphaeroidea (Möller)
	Pseudostaffella cf. *antiqua* (Dutkevich)
Rugosa	*Amygdalophylloides ivanovi* (Dobrolyubova)
	Caninia sp. nov. A.
	Cyathaxonia sp.
	Siphonodendron aff. *annulatum* (Lonsdale), Heritsch
Tabulata	*Chaetetes radians* Fischer, Heritsch
	Chaetetes svalbardicus Heritsch
	Cladochonus bacillaris McCoy, Heritsch
	Syringopora ramulosa Goldfuss, Heritsch
	Syringopora sp. A.
Echinoderma	Echinoid spines
Brachiopoda	*Choristites* sp. or spp., abundant
	Dielasma sp. or spp.
	Dictyoclostus sp.
	Linoproductus sp.
	Spirifer ? *fasciger* Keyserling
	"*Spiriferina*" *insculpta* Phillips, Holtedahl
Mollusca	*Sanguinolites* sp.
	Indeterminate Lamellibranchs
	? *Bellerophon* sp.
	Indeterminate gasteropods

The age of these as a whole is clearly Moscovian, the fusulinids suggesting a variety of Moscovian horizons ; as will be seen the overlying beds are topmost Moscovian.

(*d*) *Lower Wordiekammen Limestones* ("*Black Crag*")

The base of the Wordiekammen Limestones is defined by a conspicuous marker horizon, the "Black Crag", which varies from a shell fragment limestone at the base up into fine grained detrital or porcellanous limestones. A breccia is found locally above these limestones. The thickness is about 30 m. The lower boundary is a well defined and regular surface, generally conformable or with slight

disconformity on the beds beneath. The following have been identified :—

Fusulinidae	*Ozawainella* sp. or spp.
	Wedekindellina sp. or spp.
Rugosa	*Bothrophyllum conicum* Trautschold s.s.
	Caninia calophylloides (Holtedahl)
	Caninia hoeli (Holtedahl)
	Caninia nikitini Stuckenberg
Tabulata	*Roemeripora wimani* Heritsch var. of Wang
	Syringopora ramulosa Goldfuss, Heritsch
	Syringopora sp. A.
Brachiopoda	*Productus* (*Waagenoconcha*) ? *humboldti* d'Orbigny, Frebold ?
	Echinoconchus elegans McCoy
	Strophalosia sp.
	Spirifer sp.
Bryozoa .	*Ramipora* cf. *hochstetteri* Toula
	Geinitzella sp.
	Fenestella foraminosa Nikiforova var.
	Fenestella stschugorensis Shulga-Nesterenko
	Fenestella plebeia McCoy
	Rhombopora bigemmis Keyserling
Mollusca	*Palaeolima* sp.
	Cyprocardinia cf. *sinensis* Chao

From R64, a locality on the shore just south of the fault at Lat. 78° 30′, the following collection was made and indicates that the horizon is probably Black Crag.

Fusulinidae	*Fusulinella eopulchra* Rauser ?
	Ozawainella sp.
	? *Pseudostaffella sphaeroidea* (Möller)
	Wedekindellina sp.
Rugosa	*Bothrophyllum conicum* Trautschold s.s.
	Caninia calophylloides (Holtedahl)

The fusulinids and corals, especially *Wedekindellina* and *Bothrophyllum conicum*, and the absence of *Triticites*, indicate a topmost Moscovian horizon ; but these fossils are known from one locality besides R64 so that some diachronism is possible. The remaining rugose corals and bryozoa suggest links with higher horizons.

(*e*) *Lower Wordiekammen Limestones* (Main development)

Above the Black Crag follow about 100 m. of similar pure massive limestones partly detrital, partly porcellanous and often crag-forming. They are distinguished from the Black Crag by being less massive, and by their fossils as follows :

Fusulinidae	*Triticites* cf. *osagensis* Newell
	Schubertella sp.
Rugosa	" *Amygdalophyllum* " *ivanovi* Dobrolyubova
	Caninia calophylloides (Holtedahl) (abundant)
	Caninia sp. nov. B
	Siphonodendron schrenki (Stuckenberg)
Tabulata	*Roemeripora wimani* Heritsch
	Roemeripora wimani Heritsch v. *fasciculata* Wang MS
	Syringopora sp. A.

Brachiopoda	? *Chonetes* sp.
Trilobita	*Ditomopyge* sp.
	gen. et sp. indet.

This fauna is distinguished by the absence of Fusulininae and the presence of *Triticites*. This clearly gives an age in the *Triticites* Zone of the Upper Carboniferous. The *T.* cf. *osagensis* listed above is *T. ohioensis* Rozovskaya (non Thompson), of the top *Teguliferina* horizon (Rozovskaya, 1950).

(*f*) *Mid Wordiekammen Limestones*

In the middle of the Wordiekammen Limestones is a black band of bituminous fusuline limestone. This is the most conspicuous of such bands and is identifiable in the vertical sections in Gee *et al.* (1952) as follows : best seen in the upward continuation of Section F as a 26 ft. band about 350 feet above the base of the Black Crag (Singleton's Campbellryggen North Section, p. 328); section H at about 400 feet ; I at 250 feet ; J at 450 feet ; downward continuation of section O about 560 feet below the top of Limestone B. The following fossils came from this band :—

Foraminifera	*a*	*Cribrostomum* cf. *longissimoides* Lee and Chen
		Triticites arcticus (Schellwien) abundant
	b	*Cribrostomum* sp.
		Bigenerina sp.
		Schwagerina anderssoni (Schellwien)
		Triticites sp. A
		Schubertella sp.
		Fusulinella usvae Dutkevich
	c	*Schwagerina* cf. *anderssoni* (Schellwien)
		Triticites sp. A
		Fusulinella usvae Dutkevich
Rugosa		*Caninia calophylloides* (Holtedahl)
		,, *intermedia* (Toula), Heritsch non Huang
		,, *nikitini* Stuckenberg
		,, *sophiae* Heritsch
		Gshelia rouilleri Stuckenberg emend. Dobrolyubova
		? *Lophophyllidium proliferum* (McChesney)
Tabulata		*Cladochonus bacillaris* McCoy, Heritsch
		Syringopora sp. A
		,, sp. B.
Brachiopoda		*Dictyoclostus* cf. *americus* Dunbar and Condra, Wang
		Marginifera pusilla Schellwien, Wang
		Rhynchopora wynni (Waagen), Wang
		Choristites cf. *supramosquensis* Nikitin, Wang
Mollusca		*Pseudomonotis* sp.
		Stephanozyga sp.
		Naticopsis sp.
		Bellerophon sp.

The fossils on which this list is based were collected without expectation of faunal subdivision within this black band, but two foraminiferal samples have shown such subdivisions to exist, one giving list *b* and

the other list *c*. While list *a* from eight samples, and the majority of the macrofossils, indicate the Upper Carboniferous *Triticites* Zone, lists *b* and *c* indicate the Lower Permian *Pseudoschwagerina* Zone. The Carboniferous Permian boundary is thus seen to lie within this bed.

(*g*) *Upper Wordiekammen Limestones*

This is a series of crag-forming, chiefly shell fragment, limestones similar to the Lower Wordiekammen Limetones; at the top they include the prominent marker horizon " Limestone B ". The thickness varies between about 100–200 m. The following fauna has been identified :—

Foraminifera	*Cribostomum* sp.
	Cribostomum cf. *longissimoides* Lee and Chen
	Palaeotextularia sp.
	? *Parafusulina lutugini* (Schellwien)
	Schubertella sp.
	Schwagerina cf. *anderssoni* (Schellwien)
	„ *princeps* Ehrenberg, Dunbar and Skinner
	„ *schwageriniformis* (Rauser *et al.*)
	„ cf. *emaciata* (Beede)
	? *Triticites arcticus* (Schellwien)
Porifera	*Pemmatites latitubus* von Dunikowski
Rugosa	*Caninia calophylloides* (Holtedahl), uncommon
	„ *intermedia* (Toula), Heritsch non Huang
	„ *nikitini* Stuckenberg
	„ sp. nov. B
	Diphystrotion hyporiphaeum Porfiriev
	„ *mirabile* Porfiriev
	Gshelia rouilleri Stuckenberg emend. Dobrolyubova
	Siphonodendron sp. nov.
	„ *schrenki* (Stuckenberg)
	Timania schmidti Stuckenberg and vars., abundant
	Timania sp. nov. A
	Tschussovskenia capitosa Dobrolyubova
	Wentzelella grandis (Heritsch)
	„ *kunthi* (Stuckenberg), Heritsch
	„ cf. *magnifica* Porfiriev
Tabulata	*Hayasakaia elegantula* (Yabe and Hayasaka)
	Roemeripora wimani Heritsch
	„ „ Heritsch var. A
	Syringopora multattenuata Tschernyschew, Wiman
	„ *parallela* Fischer, Heritsch
	„ *ramulosa* Goldfuss, Heritsch
	„ *tschernyschewi* Stuckenberg, Heritsch
	„ sp. B
Brachiopoda	*Streptorhynchus* sp., Wang
	? *Derbyia grandis* Waagen
	Chonetes latesinuata Schellwien, Wang
	Chonetes sp.
	Lissochonetes sp.
	Productus cora d'Orbigny, Waagen 1884, Wiman, non Holtedahl
	„ *koninckí* de Verneuil, Wiman
	„ (*Linoproductus*) *lineatus* Waagen
	Cancrinella cancriniformis (Tschernyschew), Wang
	Productus (*Waagenoconcha*) ? *humboldti* d'Orbigny

	Dictyoclostus taiyuanfuensis (Grabau), Wang
	Marginifera pusilla Schellwien, Wang
	Rhynchopora nikitini (Tschernyschew), Wiman
	,, sp., Wang
	" *Camarophoria* " sp.
	Choristites sp.
	Martinia semiglobosa Tschernyschew, Wang
	Squamularia guadalupensis (Shumard) s.s.
	Athyris sp., Wang
	Spirigella sp., Wang
	Dielasma sp.
Bryozoa	*Fenestella tenuiseptata* Shulga-Nesterenko
	Fenestella yabei Reed
	Polypora krutovi Stuckenberg
	,, cf. *kolvae* Stuckenberg
	,, *ornata* Waagen
Mollusca	" Orthoceras " sp.
	" *Pecten* " sp.
	Conocardium norini Chao
	Modiola sp.
	Gasteropods indet.

Taking the fauna as a whole the Upper Wordiekammen Limestones seem to include the whole of the *Pseudoschwagerina* Zone. They pass down to the *Triticites* Zone in the Mid Wordiekammen Limestones and perhaps up to the *Parafusulina* Zone in Limestone B, where ?*Parafusulina lutugini* occurs in one sample. The various *Schwagerina* species characterize particular horizons, but there are as yet too few occurrences to allow of reliable subdivision.

(*h*) *Upper Gypsiferous Series*

This series comprises gypsum, dolomites, shales, sandstones, and some limestones which contrast by their scree-covered outcrops with the prominent crag-forming beds above and below. The Series begins above " Limestone B ", and varies in thickness between about 200 and 300 m. The following have been found :—

Brachiopoda	*Productus cora* d'Orbigny, Waagen 1884, Wiman, non Holtedahl
	,, (*Linoproductus*) *koninckí* s.l.
Mollusca	? *Bellerophon* sp.
	Gasteropods indet.
	? *Schizodus* sp.
Vertebrata	*Cladodus* sp.

The fauna is sparse but *Productus* (*Linoproductus*) *cora* may link this formation with the underlying Upper Wordiekammen Limestones rather than with the overlying Brachiopod Cherts.

(*i*) *Brachiopod Cherts*

The base of the Brachiopod Cherts is defined by a conspicuous horizon—" Limestone A "—which marks a complete change of facies from the underlying Upper Gypsiferous Series with which however it appears to be conformable. We have no fossils from the upper part of

the succession of 300 m. in Bünsow Land. We may look south of Sassenfjorden for comparison with Marmierfjellet (see II (*j*) below). Our fossils are divisible into two groups which are found to correspond closely with the lower two of the three divisions of the Festningen section (see III (*d*) below). We therefore divide the Brachiopod Cherts into three divisions—Lower, Middle, and Upper, the fossils below being listed only from the Lower and Middle divisions.

The Lower Brachiopod Chert Fauna

Rugosa	*Euryphyllum* sp.
Tabulata	*Syringopora multattenuata* Tschernyschew, Wiman
Brachiopoda	*Athyris royssiana* Keyserling, Wiman
	"*Camarophoria*" sp. ?
	Cyrtina septosa Phillips, Wiman
	Dielasma plica (Kutorga), Wiman
	Marginifera involuta Tschernyschew
	Productus boliviensis d'Orbigny, Frebold
	,, *inflatus* McChesney, Tschernyschew and Stepanov, 1916
	,, (*Horridonia*) *timanicus* Stuckenberg
	,, *impressus* Toula, Wiman
	,, *koninckii* de Verneuil, Wiman
	,, *weyprechti* Toula, Wiman
	,, (*Linoproductus* ?) *svalbardensis* Frebold
	,, (*Waagenoconcha*) *payeri* Toula, Frebold
	Dictyoclostus gruenewaldti (Krutov), Wang
	Productus uralicus Tschernyschew, Frebold
	Rhynchopora nikitini (Tschernyschew)
	Streptorhynchus kempei Wiman ex Andersson MS.
	,, *macrocardinalis* Toula, Wiman
	,, *triangularis* Wiman
	Spirifer fasciger Keyserling, Wiman
	,, *tastubensis* Tschernyschew ?, Wiman
	Spiriferella draschei (Toula)
	,, *keilhavii* (von Buch), Frebold
	,, *parryana* (Toula), Frebold
	,, *polaris* (Wiman)
	Neospirifer marcoui (Waagen), Wang
Mollusca	*Aviculopecten* (*Deltopecten* ?) *mutabilis* Licharew

The Middle Brachiopod Chert Fauna

Porifera	*Pemmatites arcticus* v. *macropora* von Dunikowski
Rugosa	*Amplexicarinia* cf. *smithi* Heritsch
	Lytvelasma geinitzii (Toula)
	,, *nordenskioldi* (Toula)
	Polycoelia ? *heintzi* Heritsch
	Timania sp. nov.
Brachiopoda	*Athyris royssiana* Keyserling, Wiman
	"*Camarophoria*" sp.
	Dictyoclostus uralicus (Tschernyschew) Wang
	Productus (*Horridonia*) *pseudohorridus* Wiman
	,, *impressus* Toula, Wiman
	,, (*Waagenoconcha*) sp.
	Spirifer fasciger Keyserling, Wiman
	,, *ravana* Diener, Frebold
	Spiriferella draschei (Toula)
	"*Spiriferina*" *expansa* Tschernyschew

Bryozoa	*Fenestella bifida* Eichwald
	,, cf. *chapmani* Crockford
	,, *exserta* Laseron
	,, *foraminosa* Eichwald, Nikiforova var.
	,, *lunatiostellata* Shulga-Nesterenko
	,, *permiana* Stuckenberg
	,, *pseudovirgosa* Shulga-Nesterenko
	,, *pulcherrima* Shulga-Nesterenko
	,, *pulchradorsalis* Bassler
	,, cf. *quadratopora* Shulga-Nesterenko
	,, *schischovae* Shulga-Nesterenko
	,, *simulatrix* Crockford
	,, *solida* Shulga-Nesterenko
	(and other Bryozoa not identified)
Mollusca	? *Aviculopecten* cf. *mutabilis* Licharew and cf. *hiemalis* Salter, Frebold
	Pecten (*Pseudomusium*) cf. *ufaensis* Tschernyschew, Frebold
	Pecten sp. indet. ex aff. *siriceus* de Verneuil, Frebold

The coral assemblage is typically Artinskian, and according to Mr. T. G. Miller (private communication) the Bryozoa of this middle fauna show Sakmarian to Artinskian affinities.

(*j*) *Previously described faunas from central Vestspitsbergen*

From Nordenskiöld (1876) and Nathorst (1910) it is clear that Isfjorden long provided convenient access to the shores of central Vestspitsbergen and many fossils have been recorded from the area. Unfortunately, however, very few of the fossils described have been located in detailed sections.

Nathorst (1910) described a dark, bituminous, stinking, fusuline limestone found on the S.E. shore of Tempelfjorden in 1882. It might appear that the list of fusuline species he quotes from Staff and Wedekind come from this band, but it is clearly a compilation and the latter authors (1910) refer to a locality by Mimerbukta whence comes the only material approximately localized and figured, but not identified (their Plate II, figs. 1 and 4). These sections appear to show *Triticites arcticus* or perhaps *Schwagerina anderssoni* and will thus belong to a horizon about Mid Wordiekammen Limestones.

Other observations may suggest a widespread conspicuous black fusuline limestone—the "Foraminiferensapropelit" or "Fusulina" Limestone (Major *et al.*, 1956). However, we have found more than one distinctive fusuline horizon. Bates and Schwarzacher (1958) use such "Fusulina" Limestones in their lithological correlation from Billefjorden through their own section E of Ekmanfjorden to Holtedahl's section at Brøggerhalvøya. We would expect their horizon to be correlated with the middle and not the upper of the three bands shown in their section D (from Gee *et al.*, 1952) i.e. with the Mid Wordiekammen Limestones.

Other Foraminifera recorded from the Fusulinenkalk of "Spits-

bergen" (Nathorst, 1910, p. 335) are "*Valvulina, Saccammina, Tetrataxis, Bigenerina* etc."

Padget (1954) described the following corals collected by Winsnes from localities in Bünsow Land and south of Tempelfjorden from horizons correlated with those of Gee *et al.* Forms definitely not recorded by us are starred.

Wordiekammen Limestone horizons : cf. *Campophyllum kiaeri** ; *Caninia holtedahli** ; *C.* cf. *calophylloides* ; *Roemeripora wimani* ; *Syringopora ramulosa* ; *S.* cf. *reticulata**.
Upper Gypsiferous Series : *Lithostrotion* (= *Petalaxis*) *timanicus*.
Brachiopod Cherts : *Rotiphyllum geinitzi* ; *Hapsiphyllum* ? *svalbardicum** ; *Cladochonous* aff. *bacillaris*.

Wiman (1914) reviewed the available collections and literature on brachiopods from Svalbard and of 91 species listed he gives 24 from localities in inner Isfjorden, of which the following six are not listed above. Some of these identifications are already second-hand. His localities are summarized below by numbers and only (1) overlaps with our area.

Spiriferina saranae (1) ; *Reticularia lineata* (2) (4) ; *Productus duplex* (4) ; *Productus aagardi* (1) (2) (3) (4) ; *Chonetes capitolinus* (5) ; and *Marginifera typica* var. *septentrionalis* (5).
Localities : (1) Gipshuken and Tempelfjorden e.g. Bjonahamna, (2) Flowerdalen, (3) Skansbukta, (4) Kapp Wijk and "Wijk Berg", and (5) Kapitol.

A section at Marmierfjellet was measured in 1908 by Högbom and Wiman and gives lithological divisions of a 204 m. succession from "Spiriferenkalk" up to the Eo-Trias. This usefully supplements our succession in Bünsow Land where about 300 m. Brachiopod Cherts do not appear to reach the top. Wiman (1914) records only 12 species from anywhere south of Sassenfjorden and all 12 are recorded from the "Spiriferenkalk"; 10 of these are characteristic of Limestone A at the base of our Brachiopod Cherts.

Frebold (1937) describes a fauna from a horizon (No. 5) in the succession at Gangerolvfjella (S.W. Dickson Land) collected by Höeg.

Spiriferella keilhavii ; *Streptorhynchus* sp. ; *Waagenoconcha* cf. *humboldti* v. *iriginae* ; *Horridonia timanicus* ; *Linoproductus impressus* ; *L. konincki* ; *Productus inflatus* ; *Chonetes capitolinus* ; *Pecten* (*Aequipecten* ?) *keyserlingi*.

Six of these brachiopods appear in "Limestone A" of Billefjorden and the horizon may thus be correlated with the Lower Brachiopod Cherts and so enlarge the known fauna from that horizon.

III. Correlation within Svalbard

Widespread facies changes took place in a tectonically stable area of slow deposition, and these, together with good exposures often in

flatlying beds, have made both local and distant correlation possible. The most convenient general work of this nature is by Orvin (1940). In addition to a stratigraphical review his Plate II includes some sections not described elsewhere. However, local studies have shown that diachronism is not to be ruled out and there is some advantage at this stage in reviewing the palaeontological evidence by itself.

(*a*) *Bjørnøya* (Bear Island)

According to Horn and Orvin (1928) the succession is :—

U. Trias (Carnian)
Spirifer Limestone
Cora Limestone
Fusulina Limestone
Yellow Sandstone
Ambigua Limestone (with " *Spirifer* " *supramosquensis*)
Red conglomerates
Culm Sandstones
Tunheim Series (? U. Devonian)
Miserie Series (U. Devonian)

In comparison with Spitsbergen, Bjørnøya is noteworthy for the apparently conformable succession from Upper Devonian through Carboniferous plant beds and up to the " Fusulina " Limestone. There are angular unconformities at the base of the Cora Limestone and of the Spirifer Limestone and there is a hiatus before the Upper Trias.

Plants collected by Nordenskiöld in 1868 at a locality which appears from the map and section to be north of the Engelskelva include *Calamites* sp., *Lepidodendron veltheimii*, *Cardiopteris* spp., *Stigmaria ficoides*, etc., and were correctly described by Heer (1871) as of Lower Carboniferous age. Heer however included these coal-bearing beds in his Ursa-stufe, in a table in which he used Culm-stufe for some siliceous beds above the Cyathophyllum and Spirifer Limestones. Nathorst (1902, p. 7) claimed to have collected specimens of *Cyclostigma* from this same locality which he called E, but which he described as being on the south side of the mouth of Engelskelva ; Nathorst then described his well-known Upper Devonian *Archaeopteris* flora from this and five other localities, concluding that all the plant-bearing beds of the Ursa-stufe belonged to the Devonian. As recorded by Antevs and Nathorst (1917) Culm with a coal 1·85 m. thick was discovered in borings in the north of the island in 1916 ; the flora included *Sphenopteris bifida*, *Cardiopteridium spetsbergense*, *Adiantites* sp. and *Stigmaria ficoides*. Its relation to the Devonian has apparently not yet been worked out further than is recorded by Horn and Orvin (1928), as the northern part of the island is much faulted and there are marked thickness changes. Although Heer's determinations may have included some Devonian forms his conclusion that Lower Carboniferous occurs in Bjørnøya was correct.

Sen (1958), in redescribing some of Nathorst's " Upper Devonian " megaspores, lists *Triletes* (*Tuberculatisporites*) *mammillarius* and some other Namurian-Westphalian species. These spores are also from Engelskelva and it seems more likely that they come from at least Namurian rocks than that the spores are long ranging in this one area as Sen suggests.

The Fusulina Limestone appears from its fusulinids to be of approximately the same horizon as the Mid Wordiekammen Limestones.

No further palaeozoological evidence for the age of the higher beds is available since Wiman, 1914. He took the Cora Limestone (Andersson, 1900) as equivalent to part of the Cyathophyllum Limestone of Spitsbergen and the Spirifer Limestone in each place as equivalent. Grabau (1931, p. 422) on the other hand argues from Wiman's lists that the Cora Limestone is equivalent to the Spirifer Limestone of Spitsbergen (and to the Schwagerina Limestone of Russia); the Spirifer Limestone of Bjørnøya being equivalent to the Productus beds of Spitsbergen. It is clear that the Cora Limestone must be post *Triticites* Zone but little more can be certain without further work.

(*b*) *South Spitsbergen*

Material collected from two formations (one of which is very fossiliferous without known stratigraphical relations) in Sørkappøya by Hoel and Werenskiöld, yields 12 species according to Frebold (1937), of which 5 are recorded from the Festningen section as follows :—

Spiriferella saranae ; Spirifer ravana ; Linoproductus svalbardensis ; Waagenoconchia payeri ; Aviculopecten (*Deltopecten*) cf. *mutabilis* cf. *hiemalis.*

It is clear that this fossiliferous bed would lie in our Middle Brachiopod Cherts. Wiman (1914) records 5 brachiopods from Sørkappøya with only one in common with Frebold's list.

From inner Hornsund, Höel in 1917 collected material giving the impression of a single Permo-Carboniferous formation of about 150 m. underlying the oldest Eo-Trias. Frebold (1937) records 9 species, of which the only species certainly in common with the Festningen section were found in the upper horizons 3, 4, and 5, namely :—

Linoproductus aff. *konincki* and *cancrini germanicus ; Productus* aff. *waagenianus ; Productus* aff. *wilczeki.*

Thus there is evidence of the Brachiopod Cherts beneath the Eo-Trias as at the Festningen section. Wiman records only 4 brachiopods from Hornsund. Orvin (1940) gives a detailed lithological succession totalling nearly 500 m. of limestones between Devonian and Trias. We can find no reference to fossils from the Culm mapped to the S.W. of Hornsund (Orvin, 1940).

(*c*) *Bellsund*

In a section of 1,000 m. of Culm on the north side of Bellsund, Nathorst (1920) from material collected in 1914 by Norberg and especially in 1916 by Höel distinguished three successive floras :—

3. Diabasbucht flora with *Cardiopteridium nanum*, etc.
2. Hagerup Haus flora with *Sphenopteridium norbergii*, etc.
1. Camp Miller flora with *Adiantites bellidulus*, Sub-lepidodendra, etc.

These floras were separated by beds containing only *Stigmaria* and were quite distinct; they have not yet been indentified elsewhere. Nathorst (1914) lists small collections from North and South Midterhuken and from Robertdalen ; these collections contain *Adiantites bellidulus* and are probably closest in age to the Camp Miller flora, although they cannot be exactly matched and are in Nathorst's (1914) opinion slightly later.

Correlations with the Isfjorden area suggest that the Hagerup Haus flora may be of approximately the same age as that of the shales at Pyramiden and Linnéelva. The sandstone floras of both localities are later but do not closely resemble the Diabasbucht assemblage. Externally the Hagerup Haus flora and the Pyramiden shale flora can be compared to some extent with the Oil Shale flora of the Scottish Calciferous Sandstone.

The marine succession following was divided by Nordenskiöld (Nathorst, 1910) as elsewhere into Cyathophyllum Limestones, Spirifer Limestones (with breccias), and Productus Cherts. The relation between the base of the Cyathophyllum Limestone and the underlying Culm is obscure but the overlying beds appear to be conformable. Frebold (1935) comments on the unusual thickness of the Productus Cherts (376 m.). Of the 24 species of brachiopods recorded by Wiman (1914) from Bellsund nearly all are known from Isfjorden and all the horizons of the Brachiopod Cherts, at least, could be represented in Bellsund. Bellsund was perhaps the best known of the Carboniferous localities of Spitsbergen in the early days since de Koninck's (1846) first records of Permian fossils from Spitsbergen. Detailed lithological sections are given by Orvin (1940) from Reinodden and Ahlstrandodden.

(*d*) *S.W. Isfjorden*

Culm is found inland where the section at Linnéelva (Örretelven) yielded a good collection of plants (Nathorst, 1914) from a shale and overlying sandstone ; the sequence and flora resemble that of Pyramiden. Further south, Orustdalen, which was visited by Holtedahl in 1912, has yielded only *Lepidodendron veltheimii* and *Stigmaria ficoides*.

More than 1,000 m. of Culm is succeeded by about 1,000 m. of

Permo-Carboniferous from the upper part of which well-known collections have been made. Holtedahl (1913) records marine fossils from a number of scattered outcrops.

Stepanov (1937) described a fauna of 50 brachiopod species from the Spirifer Limestones and Productus Beds of Kongressdalen. He concluded that the two formations yield essentially one fauna which he considers as a whole and by reassessing earlier identifications argues a Kungurian and possibly Lower Kazanian age ; Frebold (1937 and 1951) rejects some of these identifications. From the same collection Nikiforova (1936) described a few bryozoans which she concluded were Artinskian.

West of Festningen steeply dipping beds are exposed in a continuous measured shore section (Höel and Orvin, 1937) which has become a standard for Spitsbergen stratigraphy and includes 300 m. of the Permian. From horizons numbered from the top down, fossils were described by Frebold (1937) and summarized in his table (pp. 60–61). Frebold (1951) concluded that these faunas as a whole range throughout most of the Artinskian and possibly reach the Kungurian. We find that his list can be rearranged in three groups as follows.

Upper horizons, 1–10

Productus ? *porrectus ; Linoproductus* aff. *konincki* and *cancrini germanicus ; Chonetes variolata ; Linoproductus* aff. *waagenianus ; Productus wilczeki ; Camarophoria* sp. No. 1; *Spiriferella keilhavii ; Productus porrectus ; Spirifer* cf. *alatus.*

Middle horizons, 12–17

Spiriferina expansa ; Spiriferella saranae ; Streptorhynchus kempei ; Productus uralicus ; Linoproductus svalbardensis ; L. weyprechti ; Waagenoconcha irginae ; Spirifer ravana ; Spirifer sp. indet. (*regulatus*-Gruppe), *Waagenoconcha payeri.*

Lower horizons, 18–23

Camarophoria sp. No. 2 (in horizons 16, 18, ? 22); *Marginifera typica* var. *septentrionalis ; Horridonia pseudohorridus ; Linoproductus duplex ; Marginifera involuta ; M. clarkei ; Linoproductus* sp. indet. (*tenuistratus*-Gruppe ?); (*Rhynchopora nikitini*); also in upper horizons *Linoproductus impressus ; Productus inflatus ; Horridonia timanicus ; Reticularia lineata ; Linoproductus aagardi* ?; *Productus boliviensis* ?; *Linoproductus mammatus ; L. cora* subsp. *planus ; Spiriferella* cf. *draschei.*

The base of this succession (bed 23) would correspond to the base of the Brachiopod Cherts. Bed 12 at the top of the middle group is equivalent to the highest fauna recorded by us from Bünsow Land. Frebold (1937, p. 63) correlated his beds 22 and 23 with a horizon at the top of the Wordiekammen Limestone. This part of his composite section is derived from Wiman's (1914) Anservika section which is faulted. We uphold the earlier correlation of beds 22 and 23 with the " Spiriferenkalk " or base of the Brachiopod Cherts in Wiman's Marmierfjellet section (See II (*j*) above).

(*e*) *N.W. Isfjorden to St. Jonsforden*

From Trygghamna Nathorst (1894) recorded *Sphenopteris bifida*. Höel collected in 1908 from one horizon and Wiman (1914) records only *Syringothyris spitzbergensis* Wiman from here.

In 1948 and 1951 collections were made from a tectonically isolated outcrop of much deformed rock in Daudmannsøyra (Baker, Forbes, and Holland, 1952) which yielded besides indeterminate caniniids, fusulinids, and brachiopods :—

? *Caninia calophylloides* (Holtedahl)
Bothrophyllum pseudoconicum Dobrolyubova
? *Caninia intermedia* (Toula), Heritsch
? *Choristites* sp.

The fauna seems to be of high Middle or low Upper Carboniferous age, equivalent to the Passage Beds or Lower Wordiekammen Limestones.

Further Carboniferous outcrops in St. Jonsfjorden yielded to Holtedahl (1913) a small fauna with *Spirifer* cf. *mosquensis* which suggested some affinity with the rich fauna of the " Mosquensiskalk " of Brøggerhalvøya (see III (*f*) below).

(*f*) *Brøggerhalvøya*

The fauna described by Holtedahl (1911) from the 1·5 m. " Mosquensiskalk " comprises 42 species of which 6 occur in the Billefjorden Passage Beds as follows : ? *Spirifer fasciger ; Spiriferina insculpta ; Productus boliviensis* d'Orbigny, Holtedahl 1911, non Wiman, 1914 ; *Choristites* sp ; *Chaetetes radians ; Cladochonus bacillaris*. Of these *Choristites* and *Cladochonus bacillaris* range up to Upper Wordiekammen Limestones. Only *Syringopora parallella* of Holtedahl's remaining 36 species is known from our collections in Billefjorden, where it occurs in the Upper Wordiekammen Limestones. The fauna of the Passage Beds (with transition to evaporite facies) is thus probably the impoverished equivalent of the " Mosquensiskalk ", which gives a downward extension to the Billefjorden succession of faunas. Holtedahl argued a Moscovian age for his fauna ; Frebold (1951) followed Stepanov (1937) and took it as Upper Carboniferous, but the fusulinid correlation of the Passage Beds with Russia confirms Holtedahl's view.

The section at Dronningfjella correlated by Bates and Schwarzacher (1958) is one of the fossiliferous outcrops inland described by Holtedahl (1913). *Caninia calophylloides* (Holtedahl) from the base of this section is characteristic of the Lower Wordiekammen Limestones.

(*g*) *Lomfjordhalvøya — Chydeniusbreen*

In 1951 Dr. M. H. P. Bott collected the following from above Raudryggen.

Fusulinella bocki Möller
Quasifusulina longissima (Möller)
? *Wedekindellina* sp.
Syringopora ramulosa Goldfuss, Heritsch

These indicate a high Passage Beds or Black Crag horizon, but *Quasifusulina* does not appear until the *Triticites* Zone in Russia.

From a section at the N.E. corner of Dracoisen collections were made at three levels above the unconformity on the Hecla Hoek.

Top 600 ft.	*Caninia calophylloides* (Holtedahl) *Siphonodendron* aff. *annulatum* (Lonsdale), Heritsch
Middle 300–345 ft.	*Caninia calophylloides* (Holtedahl) *Caninia kiaeri* (Holtedahl) v. *major* Heritsch *Cladoconus bacillaris* (McCoy) *Syringopora ramulosa* Goldfuss, Heritsch
140–152 ft. above base	*Caninia kiaeri* (Holtedahl) v. *major* Heritsch *Lithostrotionella* cf. *flexuosa* (Trautschold) *Chaetetes radians* Fischer

The whole succession may therefore lie at any horizon from Passage Beds to Lower Wordiekammen Limestones. Further East, from the N. tip of Cerneusfjellet fusulines including *Triticites* were collected 25–40 feet above the base of the section, which is 735 feet up a scree slope probably obscuring lower rocks in the same succession. The horizons almost certainly lie in the Lower or Mid Wordiekammen Limestones.

(*h*) *Lomfjordhalvøya — Lovénberget*

Brachiopods from collections by the early Swedish expeditions to Hinlopenstretet were analysed by Wiman (1914), and the following were recorded from Lovénberget :—

Rhynchopora nikitini ; Athyris royssiana ; Spiriferina saranae ; Spiriferella keilhavii ; S. draschei ; Spirifer fasciger ; S. lovéni ; Streptrohynchus kempei ; Schizophoria sp. ; *Chonetes capitolinus ; C. mölleri ; Strophalosia* sp. ; *Productus weyprechti ; P. lovéni ; P. elegans ; P. timanicus.*

These are recorded as coming from " Spiriferenkalk and Kieselgesteine ". There are 8 species in common with those from the Brachiopod Cherts of Billefjorden and nothing from lower beds ; also 6 species in common with Frebold's Festningen brachiopods. Wiman also records *Spirifer fritschi* Schellwien from Kapp Fanshawe.

(*i*) *Nordaustlandet* (North East Land)

Wiman (1914) records a similar collection from Angelinberget :—

Dielasma plica ; Hemiptychina sublaevis ; Rhynchopora nikitini ; Athyris sp. ; *Spiriferina expansa ; S. draschei ; S. polaris ; S. ravana ; S. lovéni ; Cyrtina septosa ; Streptorhynchus kempei ; Chonetes* sp. cf. *geinitzi ; Productus uralicus ; P. cora.*

This fauna is again similar to the Lower and Middle Brachiopod Cherts of Billefjorden, having 10 species in common.

One of the few recorded successions from Nordaustlandet was given by Sandford (1926) from Ulvebukta where C. S. Elton noted this succession :—

(4) At top of hill 10 feet of grey cherty limestone with *Productus porrectus;* then 140 feet obscured.
(3) 20 feet of calcareous sandstone with *Productus timanicus ;*
(2) 10 feet of cherty limestone ;
(1) at least 70 feet of grey limestone with *Productus* aff. *cora* at top and passing down below sea-level.

Productus timanicus is readily identified and suggests equivalence to the lower part of the Brachiopod Cherts (say bed 23 of Frebold's Festningen section). *P. porrectus* would indicate a higher horizon in the Brachiopod Cherts than we have seen in Billefjorden (probably equivalent to Bed 5 of the Festningen section).

IV. Palaeontological Discussion

(*a*) *The Culm Flora*

The Lycopods include *Archaeosigillaria vanuxemi* and *Lepidophloios scoticus* which are both confined to the Calciferous Sandstone in Scotland. Other species appear to represent a complex of Lepidodendron- and Bothrodendron-like forms which had not yet in Lower Carboniferous time fully differentiated the well-known Namurian and later genera such as *Sigillaria*, *Lepidophlois*, etc. Species such as *Lepidodendron heeri* and *L. rhodeanum* may therefore understandably be placed in *Sigillaria* and *Lepidophloios* respectively by different authors.

Stigmaria, which is very rare from the Upper Devonian Cyclostigma and Bothrodendron floras, perhaps appears in abundance with true Lepidodendra. Elaboration to species other than *S. ficoides* (*S. rugulosa*, etc.) occurred in later time when lycopod stem and leaf organs also become more diverse.

While Lycopods were probably the only major arborescent group, several large indeterminate compressions are not obviously referable to this group and may imply the presence of other trees.

True ferns have not been proved and the fern-like fronds may well all be pteridospermous, as several types of seed are known.

(*b*) *The Fusulinids*

The Passage Beds and Black Crag are evidently of Moscovian age (*Sub-Fusulina* and *Fusulina* Zones of Dunbar, 1940). Above the Black Crag and up to and including the *arcticus* bed of the Mid Wordiekammen Limestones the strata are of Upper Carboniferous age (*Triticites* Zone). The Upper Wordiekammen Limestones yield a variety of *Schwagerina* species which may eventually allow stratigraphical subdivision. ?*Parafusulina lutugini* at the top of the Wordiekammen Limestones may indicate the *Parafusulina* Zone of Dunbar.

The fusulinid sequence as a whole shows very strong Russian affinities. In view of the large number of species described from America it is noteworthy that so few forms have been likened to American species, while distinctively Russian forms such as *Fusulinella usvae*, *Eofusulina*, and *Quasifusulina* indicate genuine Russian affinities.

(*c*) *The Coral Faunas*

Hill (1948) summarized knowledge of the evolution of Carboniferous (and Lower Permian) coral faunas. Her discussion of Spitsbergen takes account of Heritsch's work (1939), and may now be amplified.

In Moscovian times, evaporite conditions, at least in central Vestspitsbergen, discouraged coral growth. Tabulates, e.g. *Chaetetes*, *Syringopora*, *Cladochonus*, and *Syringopora* sp. A (?*Multithecopora*) were accompanied by a few Rugose corals, chiefly solitary Caniniids; the tabulate *Roemeripora* appears in the top Moscovian. Connection with Russia is shown by the appearance of the characteristic *Amygdalophylloides ivanovi* and *Bothrophyllum conicum*. The fauna is evidently of the Caniniid-Clisiophyllid type dominant in the Moscow Basin at this time. In the *Triticites* Zone, the fauna continues markedly Caniniid in character; compound Caniniids accompany the solitary species, with tabulates similar to those of the Moscovian. In the *Pseudoschwagerina* Zone (Upper Wordiekammen Limestones), the abundant Caniniids (chiefly *Timania*) are accompanied by cerioid Lonsdaleiids. Among the tabulates, *Syringopora* and *Roemeripora* are now accompanied by *Hayasakaia*. Corals do not appear again until some hundreds of feet above the base of the Brachiopod Cherts. (Upper Artinskian or Kungurian) and are then of Hill's *Cyathaxonia* fauna.

Throughout the whole sequence examined, the affinity is always Russian, to a less extent Asiatic and European and only rarely American.

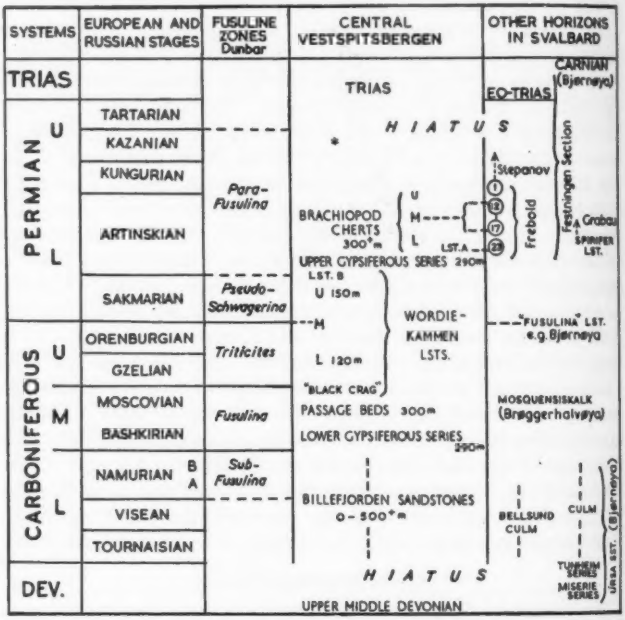
(*d*) *The Brachiopod Faunas*

Knowledge of Spitsbergen brachiopods is dominated by the work of Tschernyschew [Chernyshev] (1902) who was able to integrate them into a classic study of Russian (Ural and Timan) faunas. Wiman (1914) described all available brachiopods from Spitsbergen. Grabau (1931) in a review of Permian brachiopods, reassessed Wiman's lists. Stepanov (1937, see III (*d*) above) revised from new material the age of the uppermost faunas as Lower Kazanian while Frebold (1937) after further collection and reappraisal did not recognize anything above Artinskian; in 1951 he admitted the possibility of some Lower Kungurian.

Our identifications, made in 1953, depend largely on the above sources and thus serve only for provisional correlation within Svalbard. About 20 forms seem not to have been previously recorded from Spitsbergen. The material needs careful investigation to contribute

further to international correlation and we are indebted to Dr. K. Campbell for the following provisional comments on the material. Although the affinity with Russian faunas is unmistakable, the similarity with Greenland brachiopods as described by Dunbar (1955) is more marked. There is no evidence of anything distinctively

TABLE II.—INTERNATIONAL CORRELATION WITH SVALBARD



* Probable age of Brachiopod cherts based on Dunbar (1955).

Artinskian, and following Dunbar's correlation the Brachiopod Cherts go up to the Kazanian. Our conclusions must await the further study now in progress.

(*e*) *Bryozoa*

Mr. T. G. Miller examined some of the Bryozoa and kindly supplied the following information. The commonest genus is *Rhombotrypella*; this and other Trepostomata are long-ranged as is *Ramipora* which is also common. There are many Cryptostomata which are of more value stratigraphically; several species of *Fenestella* have been listed but there are some new genera and species which remain to be described. The fauna appears to contain rather few species and is clearly of Russian

aspect and of Sakmarian to Artinskian age. No American species have been recorded.

Nikiforova (1936) suggested Artinskian age for the highest faunas collected from Kongressdalen.

V. Stratigraphical Conclusions

Our stratigraphical conclusions are summarized in Table II where a recent recommendation (Gorsky, 1958) has been followed for the scale of stages. This enables us, without ambiguity, to refer to traditional Russian stages in terms of Dunbar's (1940) American zones, and to use a common boundary between the Carboniferous and Permian Systems, provided identity of fusuline species is established.

Spitsbergen provides a link between the Lower Carboniferous floras and between the Middle and Upper Carboniferous and the Permian faunas of the Northern Hemisphere. The succession may be summarized as follows. The Culm is distributed unevenly in Spitsbergen, being apparently limited to (*a*) a basin or trough in central Vestspitsbergen (the Billefjorden Sandstones) with a possible extension to near Lomfjorden, and (*b*) a strip from St. Jonsfjorden to Hornsund. This distribution is illustrated by Orvin, 1940, fig. 3, although it appears to us in central Vestspitsbergen to be localized in an original trough rather than by subsequent faulting. Some instability along the western margin of this trough is suggested by the Pyramiden Conglomerates (McWhae, 1953*a*) but in general the succeeding beds are conformable though with much lateral variation in facies. The Culm seems to begin a new cycle of sedimentation, filling the available basins with deltaic deposits (from Viséan or even Tournaisian times) before the widespread marine deposits overlapped on to the surrounding peneplain. There is little evidence in central Vestspitsbergen of widespread post Culm movements as reported by Orvin, 1940, especially from south Spitsbergen. It would appear that the development of evaporites (Lower Gypsiferous Series) is localized in the same basin or trough (McWhae, 1953*b*) which in its later stages may be equivalent to more normal marine deposits elsewhere—e.g. Brøggerhalvøya. The exact age of this transgression is not yet clear and may vary from place to place beginning in Moscovian; it is complete by early in the Permian succession. Certainly the Cyathophyllum Limestones and succeeding Brachiopod Cherts are very widespread and of increasingly uniform facies upwards.

In Bjørnøya, on the other hand, sedimentation was apparently continuous from Upper Devonian, through Culm, and up to the "Fusulina" Limestone, i.e. up to the Carboniferous—Permian boundary. Neither break, below nor above the Cora Limestone, has been demonstrated in Spitsbergen and until the age of the Cora Lime-

stone is known either could be related to the returning evaporite facies in Billefjorden.

Deposition of the Brachiopod Cherts throughout the whole of Svalbard appears to have been uniform. This is followed by an apparently equally widespread hiatus in the Upper Permian, either from Lower Kungurian (Frebold), Lower Kazanian (Stepanov) or later still. That higher Permian beds were deposited in the Arctic is clear from East Greenland (Aldinger, 1935). Evidence of deposition is again found in Spitsbergen with widespread older Eo-Trias (Frebold, 1939) containing an Ammonite-Lamellibranch fauna.

Thus one remarkable feature is the extreme tectonic stability of Svalbard during perhaps 60 or more million years during which deposits varying from 1,000 to 2,000 m. in thickness were formed. The general succession of evaporite facies, abundant dolomites, large foraminifera, abundant corals and brachiopods, together argue a warm climate, while the ringless tree *Dadoxylon spetsbergense* (Gothan, 1910) from Sassenfjorden indicates a low latitude. The larger size of the Bjørnøya brachiopods in comparison with both Spitsbergen and East Greenland (Dunbar, 1955) may also be significant.

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Views on Spore Nomenclature

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Abstract

Spore nomenclature and palaeobotanical nomenclature follow exactly the same rules. In both there are difficulties which must be understood historically.

In 1909 Henry Potonié published proposals concerning palaeobotanical nomenclature which were supported by F. Beyschlag, A. Engler, E. Gilg, W. Gothan, H. Harms, O. Hörich, R. Pilger, and J. Urban. They were the only *individual* additions to the rules which had been accepted at the International Botanical Congress of 1905 in Vienna. In spite of the fact that later these proposals came near to omission from the International Code, many authors followed them.

There were distinguished in the 1909 proposals :—

(1) " Good " species, genera, families, etc., which are validly published.

(2) Provisional " dilemma " groups (Verlegenheitsgruppen, groups d'embarras) for which priority is not valid.

In modern terms point (1) concerned " Organ-genera " and point (2) " Form-genera " and all epithets above them. It has become evident, however, that the two cannot always be distinguished ; some form-genera can now be transferred into organ-genera.

The International Code (1956) says (Art. PB1, Note 2) " it is necessary to distinguish both organ-genera and form-genera since the former are held to indicate a certain degree of natural affinity, while the latter may—and in many instances do—include species belonging to different families or even groups of higher rank ". Organ-genera alone may therefore be put positively in a determinate family.

It now seems certain that for both organ-genera and form-genera the type method and therefore priority must be used. Above genera the type method in palaeobotany is only to be followed with those taxa which announce by their suffix (e.g. -aceae) that they belong to the natural system of plant families ; others are still " dilemma " groups outside the type-method. It is felt in any case that the type method cannot be applied to the nomenclature of taxa above the rank of order (Art. 20).

In the selection of lectotypes for previously published taxa the automatic selection of the first specimen or species should be avoided (Int. Code, Appendix I, 4) ; selection should only be undertaken in the light of an understanding of the group concerned. An example is provided by *Trudopollis pompeckji* in which the type must be the

picture in R. Potonié, 1934, 4, 78, pl. 4, fig. 12, and not the first bad photograph of 1931 as designated by Krutzsch, 1954, p. 286.

Sometimes in the case of taxa which have been used for years without any consideration of a type, it may be better not to designate one. Such a taxon probably contained from the beginning much heterogeneous material ; the first specimens introduced were often poorly preserved and other species only temporarily included are now legitimately included in other genera. In choosing a type, all better preserved forms are found to have been put in other genera, leaving for the old " dilemma " groups only forms with which no one could work. It is surely unscientific to legitimize a genus with an unsuitable type ; likewise it is unwise to put new and good material into a genus with a bad genotype (Int. Code, PB. 6F). It is also dangerous to introduce specimens inadequately described and figured in lists of synonyms, when it is uncertain whether other material does correspond. In the case of the two taxa Sporites and Pollenites, Faegri (1956, p. 650) is of the same opinion as the present author that " they have no definite meaning to-day ". They are not suitable as names of genera in the legitimate sense of the International Code, and it would be completely arbitrary to select a genotype from such heterogeneous material. In spite of this, Andrews (1955, p. 215) believed that *Pollenites iliacus* was suitable because this species has the smallest figure number on the plate in the first publication. In addition to the advice given above, this designation of lectotype is inappropriate because *P. iliacus* was put into *Ilexpollenites* Thiergart in 1937.

Sporites was believed to have the genotype *Sporites plicatus* Schopf, 1938 (see Andrews, 1955, p. 242) although Schopf correctly suggested that a type was not necessary. In any case Sporites was erected by Henry Potonié in 1893 (see R. Potonié and Kremp, 1955, I, 31 and 33). Dawson also erected the species *papillata* and *glaber* in 1866 but they were never adequately described or figured. Sporites and Pollenites should therefore only be used in future as higher (" dilemma ") *groups* containing legitimate genera.

On the other hand, the old dilemma-genera should no longer be used ; the International Code requirements on the type-method now cover this.

Van der Hammen (1956) has designated recent pollen grains as genotypes of several new taxa, e.g. *Calluna vulgaris*. He has also given specific names to pollen grains taken from fructifications of recent plants. Neither of these procedures is valid under the International Code.

There has been considerable resistance to treating the taxa now called form-genera and form-species under the same rules as other genera, but this is now required by the International Code. It is,

therefore, unrealistic to present new systems of " dilemma " groups instead of form-genera, as Erdtman and Pant have done. In some of my earlier papers, like Erdtman I also used Sporomorphae (spm., spt.) for certain unities of sporae dispersae in the rank of genera (spt.). Since 1st January, 1953, this is no longer possible under the rules of the International Code, and must be abandoned. Balme and Henelly (1956), however, still create new taxa designated as n.spt. and n.spm. Article 54 of the International Code requires that since 1st January, 1953, for valid publication there must be clear indication of the rank of the taxon, which of course means only ranks defined in the Code. Balme and Henelly do designate genotypes and thus their sporotypes can be regarded as valid genera and their sporomorphs as valid species.

In order to handle the large number of legitimate form- and organ-genera, it is best to arrange these in a *morphographical* system which is similar to a key. As heads or divisions of this system I have chosen as far as possible names of the old " dilemma " groups which appeared earliest in the literature. These are intended to be outside the order of ranks of the International Code and therefore rules of priority do not apply ; we should, however, use the oldest names where possible and these are often the terms of Naumova. Henry Potonié (1909, p. 534) had already suggested that " dilemma " groups above the rank of genera should never bear the suffix " -aceae ", and this proposal has been introduced into the International Code.

Faegri (1956, p. 652), and also R. Potonié (1956*a*, p. 69), point out that the rules of the International Code already contain the necessary provisions except in cases where the taxa of spores are considered in relation to taxa of other organs (see R. Potonié, 1956*a*, p. 10). It is possible in certain cases to say how different organa dispersa are related, but to express this taxonomically is difficult and has already caused confusion in stratigraphy. The stratigraphical incongruity of different organs of plants from one and the same genus or family has recently been discussed (R. Potonié, 1956*b*, p. 88). This is a further demonstration of how much we need the organ- and form-genera for stratigraphical as well as botanical purposes. It would be a risk to amalgamate definitively organ- or form-genera of different organs even if the Code provided rules for it.

Because the genera and species of fossil sporae dispersae must agree with the rules of the Code, it is wrong if authors who make new proposals in this matter at once make use of them in their palaeontological papers. The proposals must first be accepted by the International Botanical Congress. I have published an excerpt from the International Code concerning Palaeophytology (Potonié, 1956*a*), although I did not then mention that a type was not necessary for

any taxon of recent plants published before 1st January, 1958 (decision of the Paris Botanical Congress, 1954, see Taxon, 4, 145 and 152). Up to that date a taxon, otherwise free of objection, is valid if it is possible to determine a type subsequently.

Although some writers to-day (Couper, Guennel, Hughes, Klaus, Thomson) emphasize the type method, there remains as before uncertainty whether a spora dispersa should be placed in a genus specially created for spores (organ- or form-genus) or in a plant genus of which the genotype is not a spore. In the latter case if a fossil spore diverges in any respect from the spores of the genus concerned it is unscientific (apart from consideration of the type method) to extend the genus without any further knowledge of the plant. Further, an author should always use a special spore-genus if he uses a specific name only valid for the spore; if the author chooses a genus where the type is for example a fructification or the whole plant, he is not allowed to choose a special specific name for it. Faegri (1956, p. 650) observed clearly that " If a pollen-grain can be identified as belonging to a known taxon, living or fossil, no special name need be or can be attached to it " (see also Potonié 1956*c*). In spite of this Rouse (1957, p. 352) places species of sporae dispersae with new names in recent plant genera. It is no improvement to make, as Rouse does, combinations like *Gleichenia concavisporites*; the suffix—*sporites* added to the specific name serves no useful purpose and should not be confused with the addition of the same suffix to generic names (see H. Potonié, 1909, p. 535). We must in this case only give the name of the genus (as did Kirchheimer and Ingversen) or mention which of the forms of the genus more or less agree with the spore by using cf. in front of the name. To give a special name to the spore is not only incorrect but superfluous. If a spore is placed in such a genus the author should be able to say which spore or spores of the genus it most resembles and why it should not be placed in another genus. Rudolph followed this method in mentioning the species with which the spore agreed so that everything possible was done.

Traverse, 1957, p. 256, says: " Potonié (1956) has clearly condemned the use of extant generic and specific names for fossil pollen." That is not right, for both are allowed and I have said so in several papers. There is, however, an important restriction; it is not suitable to use for fossil spores and pollen grains, the generic names of recent plants, if we give the spores, etc., specific names whose holotypes are sporae dispersae. When a specific name of a fossil spora dispersa is introduced into the genus of a recent plant, the specific name of the spore or pollen grain has no longer any scientific meaning. In this point I agree entirely with Bhardwaj, Brown, Faegri, Firbas, Hughes, Iversen, Kirchheimer, Rudolph, and Thomson.

Traverse says further (1957, p. 258) Potonié's argument that inclusion of new organ species in an extant genus involves a broadening of the genus does not seem correct to me, because the circumscription of the genus is established by its description. Traverse would have understood me if he had seen that also in his case a new organ species is only necessary *if it is believed not to fall* absolutely within the circumscription of the recent genus in question.

Another objection of Traverse (1957, p. 255) is that palaeobotanists studying megafossil organs have placed the organs in extant taxa. It is true that this is not absolutely forbidden by the International Code, but it should only be used if the material is more or less complete and does not consist of a very small part of the plant which may only show characters of contested diagnostic value.

Sometimes it happens that all spores of a genus show approximately the same features, indistinguishable by present methods. There is surely then no point in using a special specific name; accuracy can only be advanced to the name of a genus although that may still have considerable bearing. It is different, however, if a single kind of spore concerns several genera; then a specific name is advisable but in a genus with a spore as genotype. This occurs also with all those forms of completely unknown affinities.

Faegri (1956, p. 649) says: " The only grains that, strictly speaking can be identified to ' mother species ' and thus be assigned to their proper place and name in the system of plants, are those taken directly from anthers. Even with recent species, specific identification of pollen grains found isolated from their ' mother plant ' is only rarely possible. We have to rest satisfied with genus, tribe or even family, unless phytogeographical or other auxiliary evidence indicates that only one species is present." He thus repeats what some palaeobotanists have often said. It is hence unscientific to place the species *hiatipites* Wodehouse in the genus *Taxodium*, as it would mean that the genus is present everywhere we find *hiatipites*. Placing a spore with only a few characters in a recent genus can thus cause stratigraphic confusion (see Potonié, 1956*b*) as well as difficulties in nomenclature and taxonomy (see Potonié, 1956*c*, p. 10).

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Some Discordant Fold Structures from the Dalradian of Craignish, Argyll, and Rosguill, Co. Donegal

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ABSTRACT

The paper describes minor fold structures, from the Dalradian of Scotland and Donegal which, following their formation, appear to have suffered partial rotation. These folds lie with their axial directions at an angle to the regional fold pattern.

I. INTRODUCTION

THIS paper is concerned with the description of some minor folds which have been found to lie with their axial directions at a marked angle to the local or regional fold plunge. The initial part of the paper will describe examples from the Craignish Peninsula, in the South-West Highlands of Scotland, some 15 miles south of Oban; further examples are taken from the Rosguill Peninsula in North-West Donegal. These folds, although occurring in two widely separated areas, appear to be closely related to each other in their structure, mode of occurrence and origin.

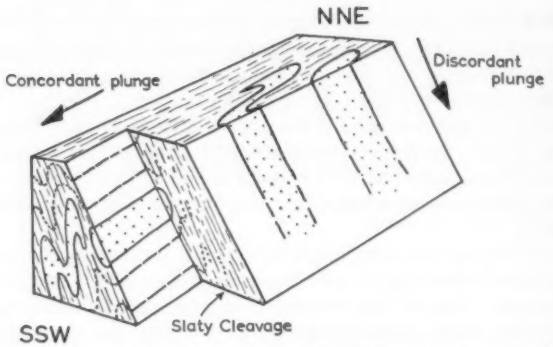
The folds which are described in this paper are discordant in that they plunge at a distinct angle to both the local and regional (i.e. concordant) fold plunge. Most of these discordant structures are detached, that is to say, they are no longer attached to their original root (Text-fig. 1).

II. DESCRIPTION OF DISCORDANT FOLDS FROM CRAIGNISH

The geology of Craignish is shown on Sheet 36 of the Geological Survey of Scotland and a brief description has been given by H. B. Muff (later Maufe) in an accompanying sheet memoir (Peach, *et al.*, 1909). The discordant folds occur in the Craignish Phyllites, which are composed of a varied succession of phyllites, quartzites, grits, and limestones with accompanying sheet-like metamorphosed intrusions (the epidiorites of Sheet 36). The Craignish Phyllites, although strongly folded locally, dip in a general eastward direction under the Loch Awe Syncline; they are deformed by a slaty cleavage which strikes NNE–SSW and dips towards the ESE at angles between 30° and 80° (Text-fig. 2*a*). Most of the minor folds and linear structures associated with this cleavage plunge at angles between 5° and 20° to the S and SSW; this general linear pattern parallels the plunge of larger folds within the Craignish Phyllites and the regional trace of the Loch Awe Syncline (Text-figs. 2*a* and *b*).

Occasionally minor folds can be found which have their axial planes lying within the slaty cleavage but their axes plunging down the slaty

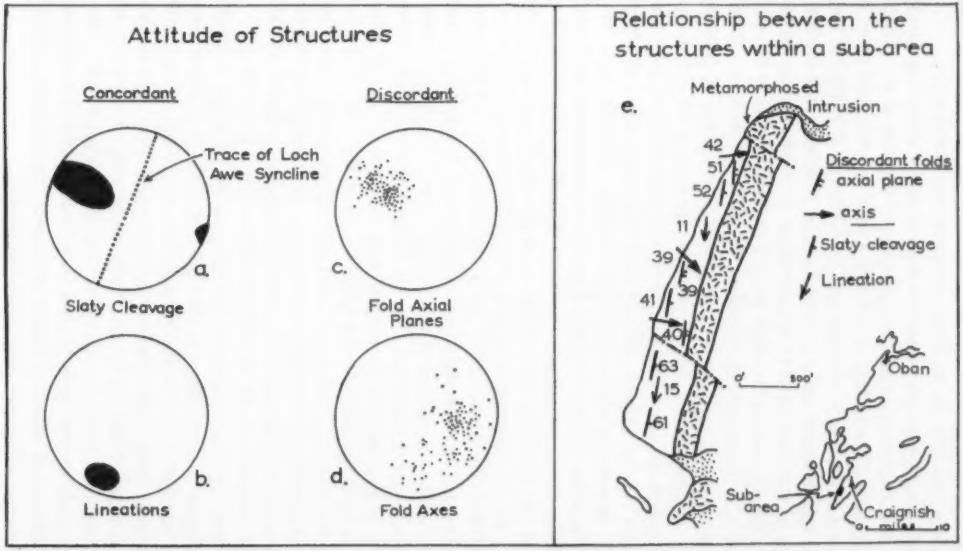
cleavage; these folds are thus discordant (Text-fig. 1). The contrast between the attitude of the concordant and discordant structures is shown on four stereographic projections (all the structural data were plotted on a 20 cm. Schmidt equal-area projection and then reduced to scale) and on a map of a small sub-area of Craignish (Text-fig. 2). The axial planes of the discordant structures are coincident with the slaty cleavage but the discordant fold axes form a girdle in contrast to the regularly plunging concordant structures. It will be seen that some of the southerly plunging discordant fold axes are very close to the concordant plunge maximum and this raises the query as to exactly when a fold can be regarded as being discordant. In Craignish, a 10° plunge



TEXT-FIG. 1.—Block diagram illustrating the relationship between the concordant and discordant structures.

deviation between a particular minor fold axis and the concordant linear structures in the immediate vicinity of the fold is generally sufficient to indicate that the fold is discordant; this point is to be discussed again.

The discordant folds are usually formed of thin beds of quartzite or limestone, between 0·5 in. and 3 in. in thickness, lying in a matrix which is generally composed of sheared micaceous or calcareous phyllites. The appearance of the folds varies but they are generally detached fold cores occurring singly or as groups in echelon (Text-figs. 3*a–f*). A particular group of folds may be joined together but the individual fold axes can plunge, both parallel to, and at a distinct angle to one another. The discordant folds have sharp axes and, in shape and style, are identical to the concordantly plunging folds. Linear structures occur on the surfaces of the discordant folds, formed by mineral parallelism and small puckers or grooving, and these all lie parallel to the discordant fold axes. Similar linear structures on the concordant folds run parallel



TEXT-FIG. 2.—Field relationship between the concordant and discordant structures. *a* to *d*. Stereographic projections ; the black areas in *a* and *b* represent 80 per cent of 4652 cleavage-readings and 3863 lineation-readings, respectively. *e*. Relationship between the structures within a sub-area of Craignish.

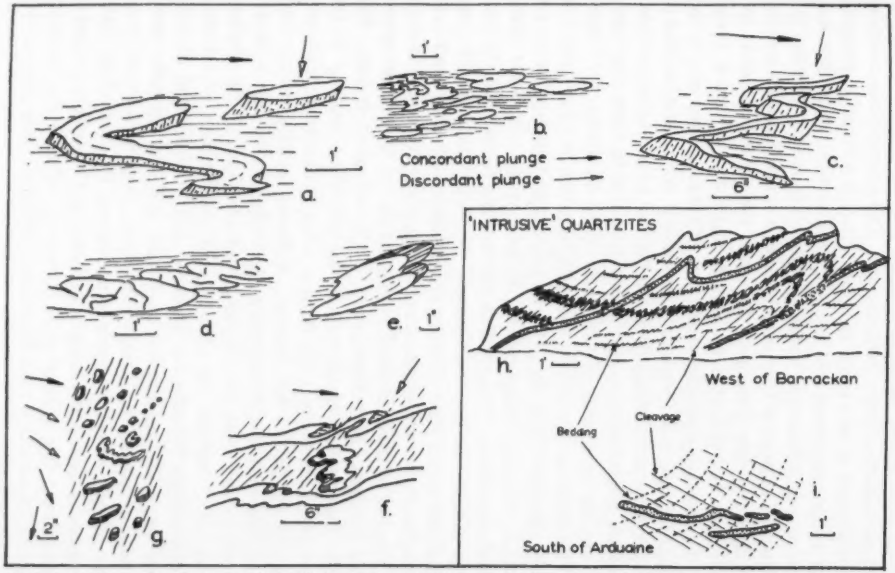
to the concordant fold axes. The sense of movement on the clusters of folds is not constant but there is a tendency for the folds to be overturned in a southerly direction (that is, resulting from a southward movement on the ESE of the folds relative to the WNW side).

The slaty cleavage in the micaceous matrix can be traced up to, and through, the discordant folds; the cleavage in the matrix close to the fold abuts against the surface of the fold and is not distorted about it. The original sedimentary lamination of the enclosing phyllites has been destroyed and shredded into a tectonic banding paralleling the cleavage.

The discordant folds most frequently occur in zones running parallel to the strike and varying in width from 2 to 20 ft. At these localities it is possible to investigate the relations between the two sets of fold axes. The concordant structures are generally composed of detached fold cores of quartzite or thin limestones plunging at 10°–15° to the south. Towards the discordant fold zone these detached fold structures become less regular in their attitude and begin to steepen in plunge while still remaining within the slaty cleavage (Text-fig. 4). This progressive swing of the fold axes from a shallow plunge to a steep plunge down the cleavage plane may take place through a distance of as little as 1 ft. (Text-fig. 3*g*). Thus, it is possible to see exactly the stage at which the change in attitude from a concordant to a discordant attitude commences. Generally, the eastern sides of these zones are characterized by these variations in fold plunge whereas the western side of the zone is composed of a competent bed of quartzite or sheet-like metamorphosed intrusion. The movement of these folds as they change in plunge appears to suggest that they are gradually transported towards the south on the eastern side of the zone. At other localities, the margins of the discordant fold zone are sharp and marked by sheared phyllites. Outside the zone, the plunge is constant whereas, inside the zone, the marginal discordant folds show a range in attitude, in general increasing in plunge towards the centre of the zone.

Some small lenticular areas of phyllites, up to 20 yards in length, have a steeper plunge than the surrounding phyllites. When these areas are mapped, it can be shown that they are masses of rock, with a steep plunge lying within shallowly plunging phyllites. The margins of these blocks are defined by thin belts of sheared phyllites running closely parallel to the slaty cleavage. This phenomenon also occurs on a very much smaller scale so that occasionally there is a difference in the attitude of identical linear structures on adjacent cleavage planes; plunge differences may be as high as 15°.

One folded structure, outcropping on the coast west of Craignish Castle (Grid Reference 17/764014), appears to give some evidence as to the mode of formation of these discordant folds. The structure is, in part, a concordantly folded quartzite lying within micaceous phyllites,



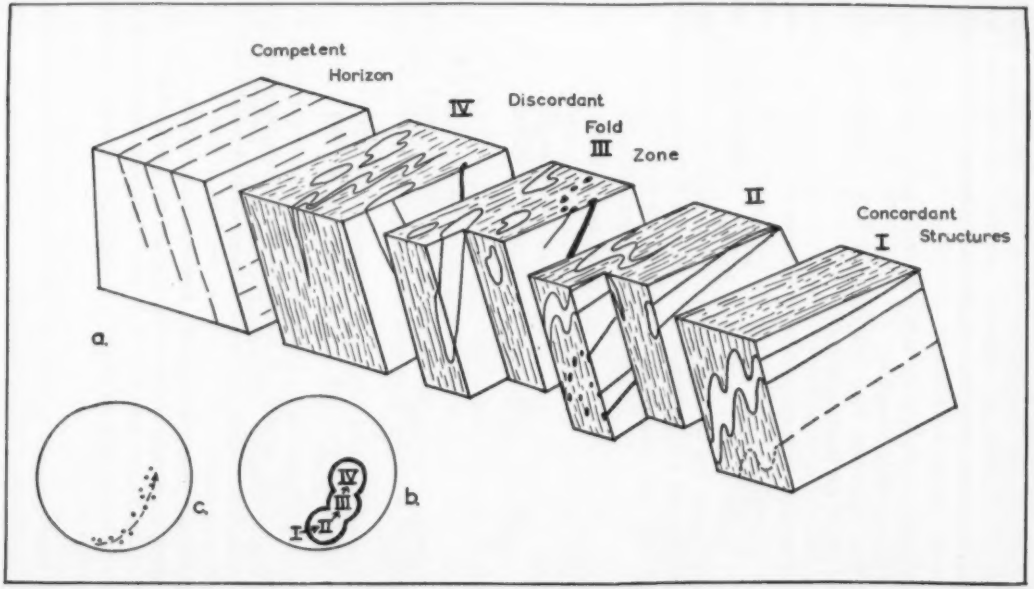
TEXT-FIG. 3.—*a* to *f*. Examples of discordant folds, Craignish. *g*. Progressive swing in plunge of detached fold cores. *h* and *i*. "Intrusive" quartzites: west of Barrackan (Grid Ref. 17/774038) and south of Arduaine (Grid Ref. 17/801093).

plunging 5° NNE and with its axial plane lying parallel to the slaty cleavage (Text-fig. 5). On the northern part of the structure there is a discordant fold which is attached to, lying against and plunging down, the eastern side of the concordant fold; the axial plane of the discordant part also lies in the slaty cleavage. The junction between these two distinct parts is very much thinned. There is a lineation plunging parallel to the concordant fold axis and the associated discordant fold has a more intense lineation, similarly paralleling its axis (Text-fig. 5*d*). This structure appears to have originated as a simple isoclinal anticline lying within the slaty cleavage. To reach the present situation, the northern part of the fold must have been twisted so that it swung within the cleavage past the eastern side of the unmoved part of the fold (Text-fig. 5*e*). Continuation of movement might have resulted in the discordant part becoming detached but this stage was not reached.

A further phenomenon occurs which is related to these discordant folds. On the west coast of Craignish, (Grid Reference 17/774038) a NW–SE joint face shows two thin beds of quartzite lying parallel to the slaty cleavage (Text-fig. 3*h*). Petrologically these quartzites are identical to other quartzites nearby, lying normally within the stratigraphical succession. The phyllites are strongly folded and the slaty cleavage parallels the fold axial planes. Neither of the quartzite beds are deformed by the slaty cleavage and consequently, they must have been emplaced after the completion of most of the folding. The more easterly bed of quartzite is sharply folded at the top of the outcrop and this fold does not distort the cleavage of the enclosing phyllites.. The quartzite then strikes southwards across the slaty cleavage of the phyllites and is connected to an echelon series of discordant fold cores on the western side of the outcrop. A second locality, on the coast south of Arduaine, (Grid Reference 17/801093) shows beds of quartzite cross-cutting both the bedding and cleavage of the phyllites (Text-fig. 3*i*); neither the cleavage nor the bedding is distorted. The relationships between the quartzite and the enclosing phyllites at these two localities appears to suggest that the quartzite could have been emplaced by actual intrusion. Although there is no obvious connection between this structure and the discordant folds, the evidence from the first locality indicates that they were formed at the same time. The style of these structures indicates the extremely plastic conditions which must have been present in these rocks at this phase of deformation.

III. Origin of the Discordant Folds in Craignish

The discordant folds which have been described in the previous section are normal folded structures identical in shape and style to the concordant folds; the only apparent difference between the two types

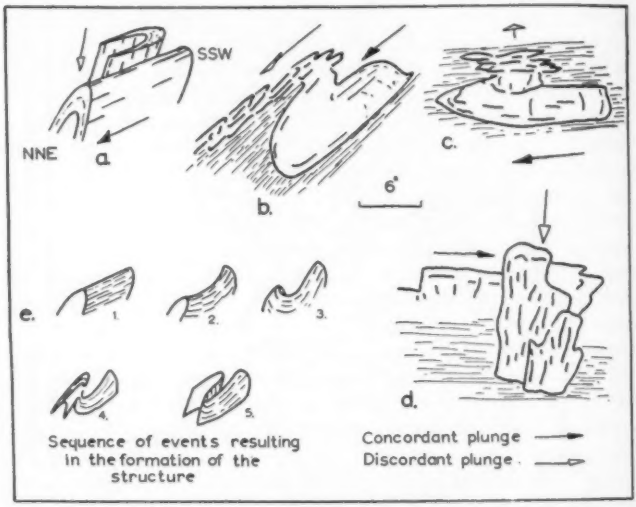


TEXT-FIG. 4.—*a*. Block diagram of a discordant fold zone. *b*. Progressive swing in fold axes in different parts of the zone. *c*. Example of this swing in the axes taken from a zone at Grid Ref. 17/774038.

of folds is their relative attitude. The field relations of these structures tends to suggest that the discordant folds could have formed by the rotation of a detached, and originally concordant, structure into a new position. The main lines of field evidence which support this conclusion may be summarized as follows:—

(i) The slaty cleavage is the axial plane cleavage to both the concordant and discordant structures.

(ii) The discordant folds are detached and, consequently, to a certain extent, are free-swimming.



TEXT-FIG. 5.—Fold apparently in the process of becoming discordant, Grid Ref. 17/764014. *a*. Diagram of the fold. *b* to *d*. Different views of the fold. *e*. Suggested sequence of events which formed the structure.

(iii) The progressive swing in the fold-axes from a shallow, concordant plunge to a steep, discordant plunge can be observed in the field.

(iv) The exposure described from near Craignish Castle, appears to show a stage in the formation of a discordant fold from an originally concordant structure.

The sequence of events resulting in the formation of discordant folds in such a manner would be as follows:—

(i) Folding of a mixed succession of competent and incompetent rocks, controlled by the east-south-easterly dipping slaty cleavage and associated with a gentle concordant plunge.

(ii) Detachment of occasional concordant folds followed by . . .

(iii) Successive rotation of those folds into a discordant attitude.

The slaty cleavage controlled the attitude of these discordant folds throughout the complete sequence of events.

The reason for the rotation of these folds is not clear. Their frequent occurrence in zones suggests that the rotation may have resulted from differential lateral movements parallel to the concordant fold axes. This sub-horizontal movement may have been some form of compensatory effect acting normal to, and resulting from, the main movements, which were in a general WNW direction. The lack of deformation of the slaty cleavage near to the discordant folds may be due to one of two factors:—

either (i) the individual folds were enclosed within thin, lenticular masses of phyllite, which were margined by slaty cleavage planes, as they rotated. Any distortion was, thus, limited to these marginal cleavage planes;

or (ii) as the fold rotated, the cleavage of the enclosing phyllites was distorted. A continuation of movement along the cleavage after the fold had completed rotation, would be sufficient to destroy the effects of this distortion.

During the field and laboratory examination of these structures various other hypotheses as to their mode of origin have been considered. However, taking into account the complete evidence, the suggested origin, described above, appears to offer the most logical explanation.

IV. Discordant Folds in Rosguill, Co. Donegal

The Rosguill Peninsula is situated in North-West Donegal, Eire, and is partly composed of a sequence of metamorphic rocks belonging to the Creeslough succession (McCall, 1954). The metamorphic and structural history of this area is rather more complex than that of Craignish and the rocks appear to have suffered greater deformation during folding. The discordant folds, which have been mapped, may be grouped into two types:—

(i) *Discordant folds apparently resulting from rotation.*

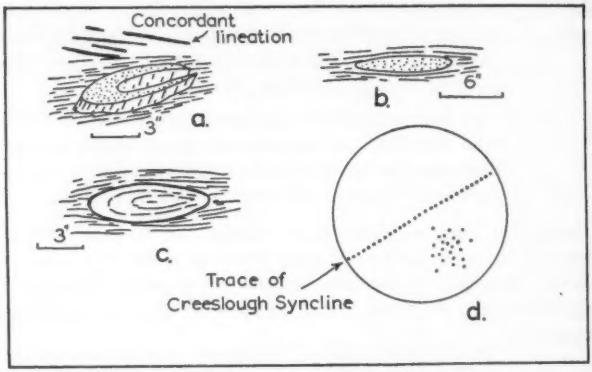
These folds are similar in appearance to many of the examples seen in the Craignish Phyllites (Text-fig. 6). They are detached folds which rest in, and plunge down, the schistosity almost normal to the trace of the major structure, the Creeslough Syncline (McCall, 1954), and the minor folds concordant to this major fold. The fold axes have a more constant plunge than those in Craignish (Compare Text-figs. 2*c* and 6*d*);

this may well be the result of the longer and more intense deformation history. These discordant folds are very similar in their appearance to detached concordant structures nearby and the structural relations of some outcrops indicate that they have probably reached their present position by rotation from a concordant attitude.

(ii) *Discordant folds resulting from refolding.*

These discordant folds are very different in their origin from the previous examples but, as some of these illustrate changes in the attitude of fold structures, they are of significance within this general context.

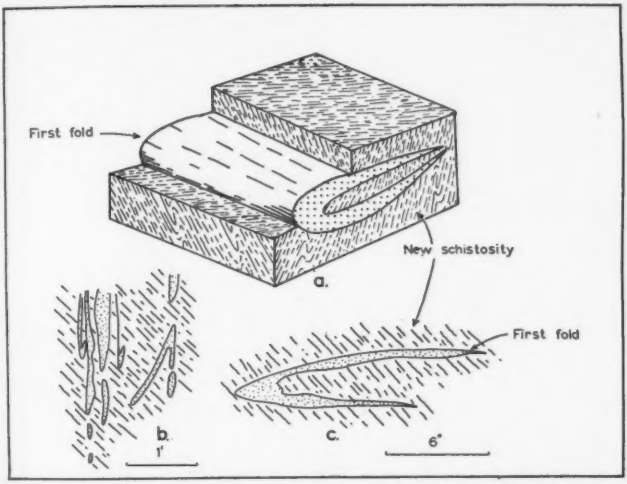
These structures are formed by the development of a new schistosity around a fold which itself is not distorted by the movements forming this new schistosity (Text-fig. 7). Thus, the fold rests with its axial



TEXT-FIG. 6.—Discordant folds, resulting from rotation, Rosguill. *a* to *c*. Actual examples. *d*. Relationship between the discordant fold axes and the trace of the major structure.

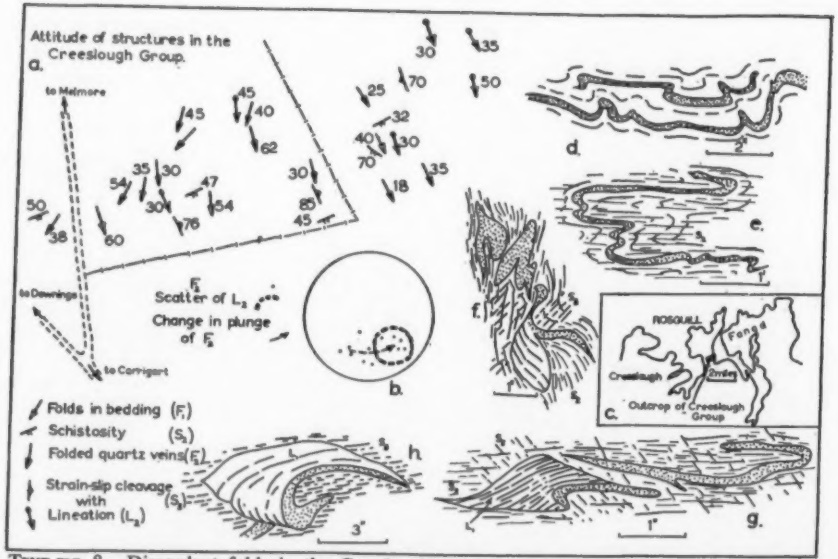
plane and axis in the original attitude, whereas the new schistosity is related to folds with a different axial plane and plunge. This type of discordant fold is clearly different from the earlier examples in that the two fold plunges, although discordant to one another, are not related to a single period of deformation but to two distinct periods. In Rosguill, these discordant folds are restricted in their occurrence to folds in quartzite or vein-quartz lying within a semi-pelitic matrix. It is generally found that the quartzites lying within a pelitic matrix are refolded by the movements associated with the new schistosity. Consequently, the semi-pelitic matrix appears to act as a restraining medium in that the penetrative effect of refolding allows the development of a new schistosity, but not the refolding of the enclosed competent horizon.

Occasionally, a more complicated situation arises in which a fold in competent material, lying within a pelitic matrix, appears to have swung into the attitude of the new schistosity. This has only been found at one locality in the south of Rosguill, in an upfold of the Creeslough Group (McCall, 1954). The outcrop of this group extends in a NE–SW direction and is paralleled by the strike of a prominent schistosity (S_2), dipping at 35° to 55° to the SE. At the western end of the outcrop (Text-fig. 8) there are some small detached folded quartz



TEXT-FIG. 7.—Discordant folds resulting from refolding, Rosguill. *a*. Diagrammatic. *b* and *c*. Actual examples.

veins (F_2) lying within this schistosity which have a grooved lineation (L_1) plunging down the schistosity; this lineation plunges parallel to the folds on which it occurs and other folds (F_1) in bedding plunging down the schistosity. Towards the east, the Creeslough Group becomes progressively more deformed by a later NW–SE strain slip cleavage (S_3); in the same direction, the folded quartz veins are seen to swing around until they come to lie with their axial planes within this strain-slip cleavage (Text-fig. 8, sequence 8*d* to 8*h*). The attitude of the grooved lineation on these detached folds changes relative to the fold axis towards the eastern end of the outcrop, and so it seems likely that the quartz veins have suffered refolding during rotation. Some groups of quartz veins are folded about two distinct axial directions although the folds lie within the same axial plane (Text-fig. 8*g*).



TEXT-FIG. 8.—Discordant folds in the Creeslough Group. *a.* Structural map. *b.* Progressive change in the attitude of F_2 towards the L_2 position. *c.* Situation of map in *a.* The sequence *d* to *h* represents examples of the folded quartz veins and their relation to the associated planar structures as seen in a traverse from the western part of the outcrop towards the east.

V. Discussion

The discordant folds which have been described in this paper appear to have been formed in two ways :—

(i) By the rotation of folds from their original position to a new, discordant position. The attitude of the schistosity enclosing the folds remains the same as that of the fold axial planes throughout the formation and subsequent rotation of the fold.

(ii) By the formation of a new schistosity in the matrix surrounding a fold, which itself, is not distorted by the refolding movements. Rarely, a partial rotation of folds into the new schistosity does occur.

Many discordant fold structures which we have examined appear to have been formed by rotation and folds of this type are apparently widespread in the Dalradian of Donegal and the South-West Highlands and also, within the Connemara Schists. It seems probable, from the recognition of discordant folds in these areas, that they are of more frequent occurrence than has hitherto been appreciated. In this paper, the term " discordant " has been used for fold structures which appear to have been formed in a distinctive manner. Clearly, it is possible for folds to be developed oblique to the major structural trend in many other ways than the particular method which has been described. Therefore, until the importance of these rotated discordant folds has been more clearly established, the authors do not consider that " discordant " should be too closely defined. However, it would be preferable if the term were restricted to folds of this broad type and not used for structures which obviously have a completely different origin. The following discussion will be restricted to the significance of the discordant folds which have been formed by rotation.

The present attitude of these folds is of considerable interest as they are markedly oblique both to the local and regional fold trends. In Craignish, the discordant folds show a marked scatter of orientation within the cleavage (Text-fig. 2) but in Rosguill (Text-fig. 6) this scatter is more closely packed. This variation in the relative distribution of discordant folds has been observed by the authors elsewhere; it is apparent that, in the more deformed rocks, these folds tend to have a regular attitude plunging approximately normal to the strike of the country rocks and to a gently plunging, concordant lineation. Because of this, it is often difficult to show that these folds have been formed by the rotation of a concordant detached structure; however, the progressive rotation can be generally demonstrated within the same area or region. The orientation of these folds is, thus, an inherent feature of their mode of formation, and they are not, in any sense, '*folds in a*', cross-folds, or the result of refolding. They are simply folds resulting from the rotation of concordant detached structures.

This rotation may have resulted from lateral movements taking place along the strike of the folded rocks parallel to the major concordant fold plunge.

It is thus, unwise to use detached fold structures in the analysis of the minor structures of a particular area, unless it can clearly be shown that rotation has not taken place. When a schistosity encloses detached folds, with the same axial plane, but with two markedly different axial directions, it is very suggestive of rotation of one set of folds. The folds which have been described in this paper are of limited size but the possibility has to be considered that very much larger tectonic structures may have resulted in a similar manner.

VI. Acknowledgments

The authors wish to thank Professor J. Sutton for reading the text of the paper. This work was undertaken while the authors held respectively, a D.S.I.R. Maintenance Grant and a Ministry of Education (Northern Ireland) Maintenance Grant.

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CORRESPONDENCE

ORIGIN OF PICRITE BLOCKS NEAR WELLS

SIR,—In 1904 Mr. H. E. Balch discovered some pieces of picrite scattered over a field at Ebbor Rocks near Wells, Somerset. They were examined by Professor S. H. Reynolds and Dr. J. S. Flett and were found to be identical with the picrite of Menheniot Cornwall. All attempts to discover the material in situ failed and it was suggested that it had been carried to Ebbor by an iceberg.

In 1922 it was brought to my notice by Mr. A. T. Davies of Keynsham that picrite had been used to repair the road leading to the G. W. R. goods yard at that village and when, in 1948, Dr. F. S. Wallis gave me a specimen of Ebbor picrite, it proved to be very similar in thin section to the rock from Keynsham. A letter to the G.W.R. brought a reply from Mr. H. A. Alexander, Divisional Engineer, Bristol, dated 25th October, 1948, in which he says "Ballast for the track not only on the Cheddar Valley Branch, but on many sections of the line comes from the Menheniot Quarries . . .". Thus there is a potential source of Menheniot picrite at Wookey Station, just over one mile from the field in which it was discovered. A recent attempt however to find picrite at this goods yard failed, the ballast and the road being at present composed of Carboniferous Limestone, together with a small proportion of various igneous rocks and slags.

When the field in question was under plough soon after the war, I was able to find on it pieces of broken brick, tile, and clinker and as all the specimens of picrite discovered at Ebbor (some 200 odd) were of about the size of road stone, being rarely more than 2½ inches long, I think we may conclude that the Ebbor picrite was probably carried to the spot where it was found, from Menheniot by human agency.

It may perhaps be worthwhile pointing out that it seems unlikely that an iceberg would freeze up pebbles in Cornwall, float north and melt them out and also that there is no known instance of ice-born rocks being found in the Mendip area.

I have to thank Dr. F. S. Wallis for placing some of this rock at my disposal and for much helpful discussion and criticism and I would also express my obligation to the Amalgamated Roadstone Corporation, Ltd. for going to considerable trouble to send me specimens of their Clicker Tor picrite from a part of the quarry believed to be in work about the turn of the century. I would also like to thank Mr. H. A. Alexander for the information he gave me.

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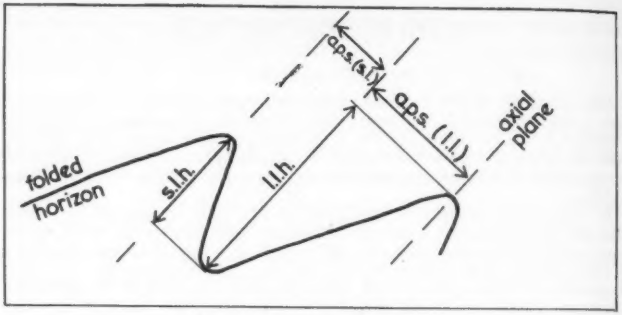
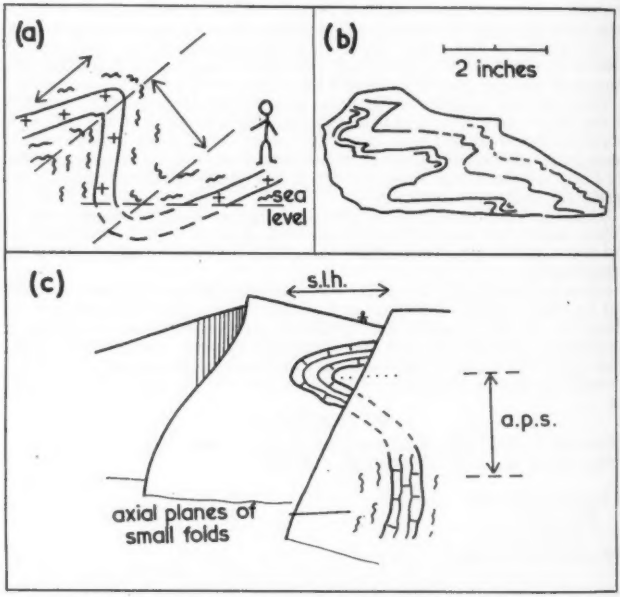
REDLAND,
BRISTOL.
18th September, 1958.

DIMENSIONS OF ASYMMETRICAL FOLDS

SIR,—In regions of highly folded rocks overturned folds may be encountered on scales that range from microscopic to regional. For descriptive purposes a semi-quantitative measure of scale is required, but the mathematical terms amplitude (A) and wavelength (λ) commonly used to specify symmetrical folds cannot be readily applied in the field to asymmetrical folds. A need for a more precise measure of the scale of such folding has arisen out of my work for the Falkland Islands Dependencies Survey. I am indebted to Mr. W. B. Harland for discussion resulting in the following proposals which have been adopted by the Survey.



TEXT-FIG. 1.—Proposed terms.



TEXT-FIG. 2.—(*a*) Minor fold in amphibolite and mica schist. Short limb height ~ 6 feet; axial plane separation ~ 9 feet; long limb height not observed.

(*b*) Isoclinal small folds in a hand specimen of quartz-mica schist cut perpendicular to the *b*-axis. Short limb height ~ ¾ inch; long limb height ~ 1½ inches; axial plane separation (short limb) ~ 0·6 inch approximately equal to axial plane separation (long limb).

(*c*) View of a major recumbent fold in marble exposed in a cliff face. Short limb height ~ 200 feet; axial plane separation ~ 70 feet.

Three lengths measured perpendicular to the axis can be used to indicate the form and scale of an asymmetrical fold. These are the short limb height (s.l.h.) and the long limb height (l.l.h.) measured parallel to the axial plane separation (a.p.s.) measured perpendicular to the axial plane (see Text-fig. 1). These terms are in essence those proposed by Challinor (1945). As the fold profile becomes increasingly symmetrical the dip of the axial plane increases and short limb height ⟶ long limb height ⟶ 2A

axial plane separation ⟶ half wavelength, $\lambda/2$.

Text-fig. 2 shows the application of the proposed terms to folds observed in the South Orkney Islands, Falkland Islands Dependencies.

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D. H. MATTHEWS.

DEPARTMENT OF GEODESY AND GEOPHYSICS,
CAMBRIDGE.
1st October, 1958.

AFRICAN EROSION SURFACES

SIR,—In a spirited controversy on the origin of certain erosion surfaces in north-east Belgian Congo, Lepersonne (1956) recognises three ages for the surfaces displayed between Nioka and Mahagi Port in Ituri District. Ruhe (1958) on the basis of his detailed geological and geomorphological studies contends that only the end-Tertiary Surface with a few isolated remnants of an earlier surface are present, but owe their varying altitudes largely to the effect of faulting. To support his interpretation, Ruhe states: "on the regional basis, Pallister (1956) has shown in Uganda that the three classic surfaces of Wayland are in reality only two." Ruhe refers to my short paper on slope form and the probable correlation with the Buganda Erosion Surface (mid-Tertiary) of a local bevel in Masaka District of Buganda known as the Koki Surface. He reads more into my interpretation than was intended or is justified. High-level, pre-Tertiary surfaces are present in western and south-western Uganda and of course such earlier surfaces are well authenticated elsewhere in the neighbourhood of the western rift. Wayland's recognition of three major peneplains is still accepted while more detailed work has shown that the original three peneplains may locally be composite in character.

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J. W. PALLISTER.

GEOLOGICAL SURVEY DEPT.,
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REVIEWS

FOSSIL MEN. A TEXTBOOK OF HUMAN PALAEONTOLOGY. By Professor MARCELLIN BOULE and Professor HENRI V. VALLOIS. Translated by MICHAEL BULLOCK from the fifth French edition. (Pp. xxv + 535, 298 illustrations.) London: Thames and Hudson, Ltd., 1957. 84*s*.

MAN'S JOURNEY THROUGH TIME. A FIRST STEP IN PHYSICAL AND CULTURAL ANTHROPOCHRONOLOGY. By L. S. PALMER. (Pp. xv + 184, 55 figures.) London: Hutchinson, 1957. 30*s*.

The first of these two books is an excellently produced English translation of the latest French edition of the late Professor Marcellin Boule's well-known volume. Professor Henri Vallois' name appears as co-author, and there is a brief introduction by Dr. Kenneth Oakley. The translation itself is competent though there are occasional infelicities and gallicisms. The text itself, however, leaves much to be desired and, in many parts of the volume, is curiously dated. Where attempts have been made to bring it into line with contemporary knowledge the effect is often given of addition and subtraction without a serious attempt at an overall, integrated, and critical revision. And such a revision the book certainly requires and deserves. Boule's original plan of presentation was admirable; too much, however, of the viewpoint and general biological attitude of the nineteen-twenties is still retained. Doubtless such retention is in part the result of a deliberate attempt by Professor Vallois to keep the flavour of the original edition. In the reviewer's opinion, however, it would have been better to have left Professor Boule's original work as the minor classic it undoubtedly was and to have produced a completely new, and current statement of our knowledge of fossil man. Such a re-writing of the volume would have resulted in a pruning out of many rather outmoded discussions. For example, there would surely have been fewer than fourteen pages devoted to *Eoanthropus*! There would also, it is believed, have been more intelligible assessment of many contemporary problems such as the status of the *Australopithecinae* and of *Pithecanthropus*.

Professor Palmer's book is a gallant attempt to present Palaeoanthropology in a graphical and quantitative manner. The results of the attempt, by the very nature of the problems and of the available data, are bound to be unsatisfying. The reader will be intrigued by the graphs and will find many stimulating and new viewpoints. He will also be impressed by the author's bravery and by his belief in the capabilities of the graphical methods described and analysed. The deductions in the arguments and the extrapolations from the graphs are sometimes startling. Everyone, however, will probably agree with Professor Palmer when he writes that " we certainly live in exciting times with definite indications of an even more exciting future ".

J. D. B.

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R. M. APPLEBY. *A Catalogue of the Ophthalmosauridae in the Collections of the Leicester and Peterborough Museums.* 47 pp., with 7 figs. Leicester Museums and Art Gallery (Dept. of Geology), 1958, no price.

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A. ROBERTS. *Geological Structures and Maps: a course in interpretation with applications for civil and mining engineers.* pp. viii + 92, illustrated and with 39 exercise maps. 2nd Ed. Cleaver-Hume Press, Ltd., 1958. Price 12*s.* 6*d.*

H. and G. TERMIER. *The Geological Drama: the formation of continents and the advance of life.* pp. 144, with 29 pls. and 10 text-figs. and maps. Hutchinson and Co., 1958. Price 30*s.*

T. WILKINS. *Clarence King: a biography.* pp. ix + 441, with 5 pls. The Macmillan Company, New York and London, 1958. Price 52*s.* 6*d.*

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—— *Bull.* 36. *Geochemical Investigation of Heavy Metal Content of Streams and Springs in the Galena Hill, Mount Haldane Area, Yukon Territory,* by R. W. BOYLE, E. L. PEKAR, and P. W. PATTERSON. 12 pp. with 2 maps. Ottawa, 1956. Price 40 cents.

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GEOLOGICAL SURVEY OF CANADA. *Bull.* 38. *Ordovician Cephalopods from Cornwallis and Little Cornwallis Islands, District of Franklin, N.W.T.*, by W. C. SWEET and A. K. MILLER. 86 pp. with 8 pls., 12 figs., and 2 tables. Ottawa, 1958. Price $1.50.

—— *Bull.* 39. *Soil Analyses as a method of Geochemical Prospecting in in Keno Hill-Galena Hill Area, Yukon Territory*, by R. W. BOYLE and C. B. CRAGG. 27 pp. with 6 figs. (including coloured maps in pocket). Ottawa, 1957. Price 50 cents.

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